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PROJECT APOLLO

LUNAR EXCURSION MODULE DEVELOPMENT STATEMENT OF WORK (U)

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MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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1.0 INTRODUCTION

1.1 Purpose. - The purpose of this document is to describe the tasks required of the Lunar Excursion Module Associate Contractor in the development of the Lunar Excursion Module and to present the technical framework within which these tasks will be performed.

1.2 Project Apollo Objective. - The objective of Project Apollo is the landing of men on the moon, limited observation and exploration of the moon by the crew in the landing area and return to earth. The Apollo development plan envisages the qualification of the Spacecraft and its Modules in a series of increasingly complex missions proceeding from sub-orbital through circumlunar to the lunar landing mission.

1.3 Mission Technique. - The lunar orbit rendezvous technique will be used to perform the lunar landing mission. Emploing this technique, the Spacecraft consisting of the Command Module, Service Module, and Lunar Excursion Module is injected into a translunar trajectory. In lunar orbit the Lunar Excursion Module with two crew members aboard separates from the Command and Service Modules and descends to a lunar landing. The third crew member remains in the Command Module in lunar orbit. After the crew performs their mission objective tasks, the Lunar Excursion Module returns to lunar orbit with the records and specimens obtained. The Lunar Excursion Module performs a rendezvous and docking maneuver with the Command Module. The crew and payload transfer to the Command Module and the Command Module, with or without the Lunar Excursion Module, is injected into a transearth trajectory by the Serivce Propulsion System.

1.4 Major Milestones. - The project milestones including those for the development of the Lunar Excursion Module are presented in Table I.

2.0 CONTRACTOR'S TASKS. - The Contractor shall be responsible for the design, manufacture, and operations in relation to the Lunar Excursion Module, its Ground Support Equipment (GSE), and associated training equipment to the extent stated in the following paragraphs. The technical framework within which the Apollo Spacecraft development shall be implemented including a description of the Lunar Excursion Module is presented in Appendix A.

2.1 Design. - The design responsibilities of the Contractor are indicated below. The use of Government Furnished Equipment or Industry Standard Equipment shall be investigated and proposed by the Contractor where feasible and practical. The Contractor shall determine and conduct the research and development program required to support his design effort. Where development tests of the complete Spacecraft are required, the Contractor shall support the Principal Contractor. He shall request the participation of NASA or other government facilities where appropriate.

2.1.1 Lunar Excursion Module. - The Contractor shall be responsible for the detail design of the Lunar Excursion Module and related test articles, mockups, and other hardware with the exception of certain Government Furnished Equipment (GFE). The systems and equipment which will be GFE are the Navigation and Guidance System (less the rendezvous radar and radar altimeter), Flight Research and Development Instrumentation System, Scientific Instrumentation System, and certain components of the Crew Equipment System (Space Suits, Portable Life Support Systems, and Personal Radiation Dosimeters). The Contractor will be responsible for integrating this Government Furnished Equipment into the Lunar Excursion Module; developing specifications for equipment performance, interfaces, and design environment; and maintaining interface control documentation in a state of validity and concurrence. The Contractor shall utilize the data submitted by the GFE contractors in the performance of this responsibility, e.g., the weight statements of the GFE contractors will be utilized without the Contractor re-estimating the weight of the GFE. The Contractor shall assist NASA in the review of the plans submitted by the GFE contractors as requested. Detailed interface responsibilities and procedures will be developed in accordance with paragraph 4.2.5 of the Program Management Section. The responsibilities of the Contractor in certain interface areas are discussed in the following paragraphs to serve as guidelines in the further development of detailed interface responsibilities and procedures.

2.1.1.1 Trajectory Analysis.- The Contractor shall be responsible for detailed trajectory analysis from lunar orbit separation until lunar orbit rendezvous directly related to the Contractor's area of responsibility. This shall include studies to optimize the lunar orbit characteristics, position of separation, descent trajectories, abort analysis, ascent trajectories, and positions of rendezvous. The overall trajectory analysis for the lunar mission will not be the responsibility of the Contractor. A final design mission will be determined based on the detailed studies conducted by the various Apollo contractors and the NASA.

2.1.1.2 Environmental Analysis.- The Contractor shall be responsible for specifying the mission environment on the lunar surface utilizing data obtained from NASA and other sources and for assessing the effects of the Spacecraft Adapter environment on the Lunar Excursion Module. The Contractor will not be responsible for specifying the natural environment except on the lunar surface. The natural environment during the other mission phases and the environment within the Spacecraft Adapter will be specified to the Contractor. The Contractor shall be responsible for the specification of the design environment for the Lunar Excursion Module GFE.

2.1.1.3 Repositioning Analysis.- The Contractor shall be responsible for the detail design of the Lunar Excursion Module mounted equipment for repositioning and mating the Lunar Excursion Module to the Command Module. The Principal Contractor will be responsible for the determination of the methods and/or devices to be used in repositioning and mating the Lunar Excursion Module with the Command Module and for the preparation of an overall specification for the associated hardware mounted on the Lunar Excursion Module. The Contractor shall design the Lunar Excursion Module mounted equipment within the overall specification of the Principal Contractor.

2.1.1.4 Mission Operational Analysis.- The Contractor shall be responsible for determining and proposing the desirability of checkout and/or operation of the Lunar Excursion Module during the translunar period of the flight. This shall include the desirability of crew access to the Lunar Excursion Module from the Command Module during this period. It shall include the determination and proposal of systems support from the Command or Service Modules

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such as power from the fuel cells or oxygen for cooling, breathing, or pressurization and the support required from these Modules while separated during the landing phase of the mission. The Contractor shall determine and propose the crew tasks related to the Lunar Excursion Module prior to separation whether they are actually performed in the Lunar Excursion Module or the Command Module. The NASA will assess and integrate the support required from the Command and Service Modules and from the crew during the various mission phases. The Contractor shall be responsible for the determination of the Lunar Excursion Module crew tasks during the separated portion of the flight including the tasks related to the operation of the Lunar Excursion Module GFE; however, the tasks directly related to the operation of the Scientific Instrumentation System and to exploration while on the lunar surface will be the responsibility of the NASA.

2.1.2 Ground Support Equipment.- The Contractor shall be responsible for the design of the GSE directly associated with the hardware which he is responsible for designing and for assuring the compatibility of all GSE directly associated with the Lunar Excursion Module.

2.1.3 Training Equipment.- The Contractor shall be responsible for the design of certain training equipment directly associated with the Lunar Excursion Module for the training of flight and/or ground personnel as required by the NASA.

2.2 Manufacturing.- The Contractor shall be responsible for the manufacture of the Lunar Excursion Module and related test articles, mockups, and other hardware with the exception of the GFE indicated above. The Contractor shall be responsible for the the manufacture of the GSE for the equipment which he furnishes and shall also furnish the training equipment required. The Contractor shall install all GFE in the Lunar Excursion Module prior to delivery. The receiving acceptance tests and systems tests of GFE will be conducted by the GFE Contractors at the Contractor's plant under the overall test direction of the Contractor. After these tests are completed, simplified checkout tests may be conducted by the Contractor. If a malfunction occurs or is suspected and additional tests are required, these will be conducted as before by the GFE Contractors working with the Contractor. Subsequent to delivery the same procedure will be followed between the various tiers of contractors involved.

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2.3 Operations.- The Contractor shall perform the prelaunch preparation and checkout of the Lunar Excursion Module working with the other contractors in the same manner as during systems testing. He shall integrate the GFE preparation and checkout and be responsible to the Principal Contractor for coordinating all Lunar Excursion Module activities with the overall Spacecraft prelaunch requirements. The Principal Contractor will integrate the Lunar Excursion Module preparation and checkout with the overall Spacecraft preparation and checkout. He shall provide personnel to support the flight operation in ground monitoring of the Lunar Excursion Module Systems and perform post flight analysis of the performance of the various subsystems of the Lunar Excursion Module.

2.4 Reliability and Quality Assurance.- As an integral part of the design, development, manufacturing and test program the Contractor shall plan and implement a reliability and quality assurance program to assure that a high level of quality is achieved in the manufacturing and test process and that considerations of mission reliability and crew safety are exhaustively treated and controlled during the design, development and test program. The Reliability Program will be developed along the lines set forth in MIL-R-27552 (USAF) and the Quality Program will be as set forth in Reference 1.

2.5 Logistics.- The Contractor shall be responsible for providing adequate logistics support for the equipment which he furnishes. Logistics support shall include all spares and transportation.

2.6 Documentation.- The Contractor shall provide the documentation described in Paragraph 4.5. All documents required shall be classified as one of three types. Type I documentation shall be submitted to the NASA for approval. Type II documentation shall not require approval, but shall be submitted for coordination, surveillance, and/or information. Type III documentation shall be retained by the Contractor and made available to authorized representatives of the NASA for review, upon request.

3.0 NASA AND OTHER CONTRACTOR RELATED TASKS. - The Lunar Excursion Module contract will be managed by the Manned Spacecraft Center of the NASA. The development of the Lunar Excursion Module will require contact with the Principal Contractor and with other contractors and government organizations. The NASA will arrange the procedures for, and will monitor these contacts. The following paragraphs define those NASA and/or other contractor tasks related to the Lunar Excursion Module for the purpose of better defining the Lunar Excursion Module Associate Contractor's tasks. NASA's responsibility as used in this document does not preclude parts of the responsibility being carried out through other NASA Contractors.

3.1 Design. - The Principal Contractor will design the Command Module, Service Module, and all Spacecraft Adapters and will integrate the Lunar Excursion Module and its associated GSE into the Apollo Spacecraft System. The Principal Contractor will utilize the data submitted by the Contractor in the performance of his integration responsibility, e.g., the weight statements of the Contractor will be utilized without the Principal Contractor re-estimating the weight of the Lunar Excursion Module. He will develop specifications for the interface between the equipment which he provides and the Lunar Excursion Module including the Lunar Excursion Module geometric envelope, attachment points, and all other mechanical and electrical interfaces. The NASA will be responsible for the detail development of the GFE which will be used in the Lunar Excursion Module.

3.2 Manufacturing. - The NASA will be responsible for providing the Lunar Excursion Module GFE and its associated GSE. The Principal Contractor will provide the Command Module, Service Module, and all Spacecraft Adapters.

3.3 Operations. - The NASA will direct the Spacecraft prelaunch, launch, flight, and recovery operations. The NASA will provide all Spacecraft launch site facilities, overall prelaunch and launch countdown procedures, flight crews, and medical support. The Principal Contractor will support the operations relative to the Spacecraft. He will checkout and prepare the Command and Service Modules and associated GSE and integrate the overall Spacecraft prelaunch operations.

4.0 PROGRAM MANAGEMENT

4.1 NASA Organization

4.1.1 Over-All Direction.- The Director, Office of Manned Space Flight Programs, is responsible for over-all direction of Project Apollo.

4.1.1.1 Spacecraft.- The NASA Manned Spacecraft Center (MSC) has been assigned system management responsibilities for the Apollo Spacecraft including Test Launch Vehicle Development and operations control and computing centers.

4.1.2 Apollo Spacecraft Project Office.- The Apollo Spacecraft Project Office of the NASA Manned Spacecraft Center is responsible for planning, supervising, and directing all activities associated with the accomplishment of the Apollo Spacecraft project. In this capacity, the Project Office is responsible for and has authority for supervision and direction of the Lunar Excursion Module development. Primary functions which will be performed by the Apollo Spacecraft Project Office include:

a. Supervision and direction of the work of the MSC Apollo Contractors.

b. Determination and implementation of technical modifications, changes, or revisions in the work undertaken by the MSC Contractors.

c. Supervision and monitoring of working relationships and resolving technical problems which may arise between various MSC Contractors, which are not directly resolved between the parties concerned.

d. Maintaining close liaison with all Apollo Contractors in order to keep fully and currently informed on the status of contract work, potential schedule delays, or problems which may delay project progress.

Responsibilities and procedures in these areas are discussed in greater detail in subsequent sections of this document. In carrying out these functions the Apollo Spacecraft Project Office will locate personnel at the site of contract work as required.

4.1.3 Apollo Procurement Office. - The Apollo Procurement Office of the NASA Manned Spacecraft Center is responsible for the negotiation, award, administration, and appraisal of MSC contracts associated with the Apollo Spacecraft Project, including the Lunar Excursion Module development. Duly appointed Contracting Officers will be responsible for negotiating and awarding contracts and for assuring the administration and appraisal of contractual performance in accordance with applicable law, regulations, and contract provisions. Technical direction which results in a change to this Statement of Work will not become effective until receipt by the Contractor of a Contract Change Order or Contract Modification issued by the Contracting Officer pursuant to the clause of the contract entitled "Changes".

4.1.4 Monitoring. - The Apollo Spacecraft Project Office will monitor all technical activities of the Contractor to provide technical direction, implementation, and coordination; to expedite the resolution of problem areas; to assist in achieving reliability goals and quality assurance; and to provide technical surveillance of design, testing, and manufacturing operations. In addition to the regular day-to-day monitoring activities three types of regularly scheduled meetings will be used for coordination and monitoring purposes. These will be called Quarterly Status, Design Review, and Systems Meetings. The Quarterly Status Meetings will consist of a formal status report to NASA Management. They will cover such items as the Contractor's organization, management, facilities, cost, etc., and will only summarize the technical status of the Lunar Excursion Module Development. The Design Review Meetings will be held on a monthly basis and will consist of a report to the MSC Senior Technical Staff. They will cover the technical philosophy of the Lunar Excursion Module Development. The Systems Meetings will be held on a biweekly basis and will consist of meetings between technical specialists at a detailed engineering level. Separate meetings will be held in areas such as Flight Technology, Crew Systems, Power Systems, Mechanical Systems, Electrical Systems, Guidance and Control Systems, Ground Support Equipment, and Ground Operational Support Systems. Contractor participation in each of the Systems Meetings will normally be restricted to not more than three regularly assigned engineers authorized to make engineering decisions for the Contractor.

Authorized representatives of the MSC shall have the right to visit Subcontractors' plants at all times during the performance of this contract for making any inspections or obtaining any required information. Such visits will be coordinated with the Contractor.

4.1.5 Coordination.- The MSC Apollo Spacecraft Project Office will arrange and coordinate all contacts and meetings and will provide for technical coordination between the NASA contractors, the Manned Spacecraft Center, other NASA organizations, and other government agencies as required to assist all levels in obtaining information data, and assistance necessary for accomplishment of the project.

4.1.6 Data Submittal.- The Contractor shall submit all technical information, documentation, and data to the MSC Apollo Spacecraft Project Office. Other simultaneous parallel paths of distribution may be specified as the need arises. All additional distribution shall be subject to prior MSC Apollo Spacecraft Project Office approval.

4.2 Contractor Organization

4.2.1 Project Organization. - The Lunar Excursion Module Contractor shall establish a strong Apollo organization headed by a Program Manager and removed from other Contractor programs to the extent necessary to prevent interference with a timely completion of the Apollo program. He shall have the responsibility and necessary authority for the accomplishment of the Lunar Excursion Module development.

4.2.2 Organization. - Consistent with good practice and to the extent necessary to preclude interference from existing or future projects, the Contractor shall adequately organize all elements, functions, and services required to accomplish the Lunar Excursion Module development into an appropriate organization responsible to the Program Manager. For each individual major subsystem, the contractor shall designate a person within his organization who will act as a single point of contact for all matters directly related to that subsystem and be responsible for its development.

4.2.3 Staff Offices. - The Contractor shall maintain, within his Apollo organization, staff offices to assure the utilization of efficient engineering methods and management practices. These offices shall include the necessary functions to adequately control the program. The functions shall consist of but not be limited to:

Program control

System integration

Subcontractor control

Cost control

Reliability Control and Quality Assurance

Documentation

NASA-MSC liaison

4.2.3.1 Engineering Changes. - A formal procedure shall be established for reviewing contract change proposals to assure that all technical, planning, and cost aspects of the proposed changes are considered.

4.2.3.2 Subcontract Administration. - A staff group of subcontract specialists covering all essential disciplines shall assume responsibility for coordination of subcontract work. The Contractor shall establish and maintain resident field offices at the plants of major Subcontractors as required.

4.2.3.3 Reliability and Quality Assurance Organization. - Personnel performing reliability and quality program functions shall have sufficient, well-defined responsibility and the organizational freedom to recognize and amend problems and to initiate, recommend, and/or provide solutions. Those responsible for the reliability and quality program shall have direct, unimpeded access to higher management and shall report regularly on the status and adequacy of the program.

4.2.4 Delineation of Organization. - A delineation of the Contractor's management organization and procedures shall be included as part of the program plan specified in Paragraph 4.3.2.1 and shall include the following:

a. The responsibilities of the various portions of the Contractor's organization.

b. The division of responsibilities between the Contractor and Subcontractors.

c. The specific program control techniques to be used.

d. The provisions for an orderly flow of communications within the Contractor's organization and with Subcontractors.

4.2.5 Contractor Interface Relations. - The Principal Contractor will be responsible for developing and documenting in detail the division of responsibilities, operating procedures, definitions, specifications, control procedures, etc., required in the interface areas common to the Principal Contractor and the Contractor. The Contractor shall support the Principal Contractor in this effort. In the interface areas related to the GFE Contractors, the Contractor, supported by each GFE Contractors, shall be responsible for developing and documenting in detail the division of responsibilities, operating procedures, definitions, specifications, control procedures, etc., required in the applicable interface areas. The NASA will monitor and approve the above effort during its development.

4.2.5.1 Principal Contractor. - North American Aviation, Inc., Space and Information Systems Division is the Apollo Principal Contractor.

4.2.5.2 Navigation and Guidance System Associate Contractor. - The Massachusetts Institute of Technology, Instrumentation Laboratory is the Apollo Associate Contractor for the Navigation and Guidance System.

4.3 Program Control

4.3.1 General. - The MSC will exercise program control through use of program planning documents, periodic reviews, PERT, cost reports and such other management tools as may be required, including frequent scheduled and nonscheduled meetings.

4.3.1.1 Periodic Reviews. - Periodic technical and management program progress reviews of all aspects of the Contractor's work will be conducted by the MSC. These reviews will be conducted at the Manned Spacecraft Center and at the Contractor and Subcontractor plants as required. These reviews are intended to encompass major developmental milestones and/or problem areas.

4.3.1.2 Mockup Inspections. - The MSC will conduct mockup inspections at the Contractor's plant. These inspections will cover the adequacy of the design of the Lunar Excursion Module, its systems, and their compatibility with other elements of the Spacecraft. Mockup inspections will progress from preliminary to final.

4.3.2 Program Planning. - The detailed program plans, schedule, and requirements prepared by the Contractor shall encompass the activities of all Subcontractors supporting the Contractor and shall indicate their relationship to each other. A common, systematic breakdown of the various elements of the project shall be used in the preparation of these plans, schedules, and requirements. These plans, schedules and requirements shall be documented as described in the following paragraphs. All plans and revisions shall be prepared in close coordination with MSC and shall be subject to approval by the MSC.

4.3.2.1 Program Plan. - This document shall be the basic document which describes the over-all plan for the development of the Lunar Excursion Module. The plan shall delineate the method by which the Contractor intends to comply with the Statement of Work. The plan shall summarize management and control functions, design and development approaches, test program requirements and plans, manufacturing, quality assurance, logistic support requiremnts and such other planning documents as are specified in the Statement of Work. It shall include master phasing charts and milestone charts for the over-all program; general management, technical, manufacturing, facilities, and support schedules; man power requirements for performance of the project; and detailed phasing charts. Each detailed phasing chart shall portray important activities, their beginning and completion points and points at which decisions must be made. The approved program plan shall be used by the Contractor to guide his efforts. Anticipated schedule problems shall be identified and the intended method for their solution indicated.

4.3.2.2 Facilities Plan. - This plan shall cover the complete requirments for facilities for the Lunar Excursion Module and shall identify those which are to be government furnished. Industrial, development, range, operations, and all other facility requirements shall be described in detail, including any necessary modifications of existing facilities. Schedules showing required availability and modification dates, and plans for accomplishing necessary design and construction shall be included.

4.3.2.3 Test Plan. - The Contractor shall provide a test plan for the entire Lunar Excursion Module development program. The plan shall cover all types of tests required including such items as significant engineering development tests, design verification tests, tests to determine operating environments or conditions, qualification tests, prelaunch tests, and flight tests. It shall outline the types and quantities of tests to be run, equipment and configurations to be tested, concepts and objectives of the tests, test locations, support requirements, major time phasing, and shall identify those which are to be performed by the government.

4.3.2.4 Manufacturing Plan. - The Contractor shall provide a manufacturing plan including such items as plans, schedules, methods, and controls.

4.3.2.5 Reliability Plan. - The Contractor shall prepare a reliability plan in accordance with Mil-R-27542 (USAF).

4.3.2.6 Quality Program Plan. - The Contractor shall provide a Quality Program Plan in accordance with the provisions of Paragraph 3.1 of Reference 1.

4.3.2.7 Maintenance Plan. - The Contractor shall prepare a maintenance plan which describes the detail requirements necessary to provide for the maintenance of all equipment throughout all phases of the program. The plan shall include maintenance during factory testing, storage, assembly, prelaunch testing, and flight testing.

4.3.2.7 Support Plan. - The Contractor shall prepare a support plan which describes his support of the Lunar Excursion Module. The Contractor's support shall be consonant with the participation of the NASA and other contractors. The support plan shall include a description of all required functions of equipment overhaul, material (spares) support, transportation, and preparation of support manuals. Material support considerations shall include the methods of selection, distribution and control of spare parts, and the disposition of obsolete spare parts. Transportation considerations shall include the total transportation including Lunar Excursion Module transportation, peculiar spare parts and GSE requiring transportation, and other pertinent transportation data. Packaging requirements shall be specified in the plan. Support manual considerations shall include requirements, scope of coverage, format, change program, and other pertinent information.

4.3.2.9 End Item Test Plan. - The Contractor shall provide an End Item Test Plan in accordance with the provisions of Paragraph 7.4.2.1 of Reference 1.

4.3.3 PERT. - The NASA PERT system will be utilized by the NASA as a management tool in scheduling, phasing, and controlling the Apollo Spacecraft program. Lunar Excurison Module PERT events, activities, and networks will be integrated with the total Apollo Spacecraft program PERT system. The NASA PERT system will be implemented and maintained in accordance with the NASA PERT Handbook.

4.3.3.1 Implementation. - The Contractor shall commence implementation of a PERT system for the Lunar Excursion Module within 30 days after letter contract award. Individual PERT networks shall be developed for each Lunar Excursion Module system and each major area of functional activity. The number of networks required and the scope of each network will be established by MSC after giving due consideration to the recommendations of the Contractor.

4.3.3.2 Reporting. - Reporting against networks shall commence after establishment and MSC approval of all Lunar Excursion Module PERT networks and shall be in accordance with NASA PERT Handbook.

4.3.3.3 PERT Event and Activities Description Document. - The Contractor shall prepare, submit, and maintain PERT Events and Activities Description Documents. The Contractor shall provide detailed descriptions of the events and activities which comprise the PERT networks required by the ASPO, MSC. The documents will be adjuncts to the PERT networks.

4.3.4 Program Milestone Reports. - The Contractor shall report program progress biweekly. Milestone reporting by the Contractor will be utilized indefinitely, although the level of milestone detail will be reduced when the PERT reporting system is implemented.

4.3.4.1 Implementation. - The Contractor shall submit a list of proposed reporting milestones to MSC for approval 6 weeks after letter contract award. The Contractor shall commence biweekly milestone reporting within 12 weeks after letter contract award. Milestones for each Lunar Excursion Module system and major area of functional activity shall be submitted. System and activity milestones shall be grouped in a manner similar to the structure of the PERT networks. The milestones shall be selected in such a manner that 25 to 100 milestones for each system or activity will be scheduled for completion during the first year of the contract. Milestones for the remainder of the program may be limited to major items.

4.3.5 Financial Management. - Financial Management Reports will be prepared and submitted monthly by the Contractor. These summary and detail cost reports will provide direct engineering and labor manhours itemized by system, in addition to the normal cost for materials and vendor items, logistics and support, tooling and manufacturing and such other cost as is required for Financial Management and Auditing, in accordance with sound cost accounting practices. In addition to each system and subsystem being reported as a category of costing, the Lunar Excursion Module contract will report each subcontract, where the total cost of the subcontract exceeds $250,000 as a separate costing category. Direct manhours charged by the subcontractors as well as labor/engineering costs incurred will be reported for the subcontracts identical in form to the Contractor's in-house effort.

4.3.5.1 Budget Forecasts.- Unlike cost incurred, Budget Forecasts are not subject to audit by MSC, but rather are required as an additional management tool for analysis and forecasting anticipated cost in the conduct of the total Project Apollo Program Financial Management operation. Quarterly budget forecasts will be required monthly. These forecasts will be prepared by the Contractor. Like the actual cost and direct manhours reported in the Financial Management

Report, the budget forecast will be reported by systems and eventually subsystems. Each Subcontract will be budgeted as a separate planning category.

4.3.5.2 Implementation. - The first cost estimates and budget forecast will be prepared and submitted by the Lunar Excursion Module Contractor to the Apollo Spacecraft Project Office 6 weeks following letter contract award.

These estimates are to be designed for review for suitability by MSC, in conference with the Contractor, for format, selection of cost categories, technique or method, Contractors and ability of the Contractor to convert departmental accounting into realistic reporting categories.

A second report utilizing the methods, techniques, and format determined adequate and suitable by MSC will be submitted by the Contractor 12 weeks after letter contract award and upon approval of MSC, monthly thereafter throughout the life of the contract.

4.3.5.3 Categories. - The categories to be reported for the financial summary and detail cost reports and for the budget forecast shall be similar, if not identical, to the functional and system networks selected for PERT and Program Management Plan reporting. It is intended that separate cost accounting and budget forecast estimates will not exceed 25 separate categories, excluding the separate reports for each sub-contract.

4.3.5.4 PERT-Associated Cost. - As soon as deemed practical, cost reporting and budget forecasting will be PERT-network oriented. It is intended to designate PERT-Associated cost in such a manner as to reduce the level of effort by eliminating other costing techniques in use at time of implementation and at the same time improving the level of effort by providing more realistic cost reporting and budget forecasting by network event groupings or major milestones activities. The determination by MSC to convert to PERT-Associated cost will be made as soon as network approval.

4.3.6 Changes. - Any plans, schedules, or requirements proposed in accordance with Paragraphs 4.3.2, 4.3.3, and 4.3.4 and any revisions or changes thereto which affect the approved schedule of contract performance or appreciably increase or decrease the cost of the contract will require prior contractual coverage.

4.4 Deliveries

4.4.1 Schedule.- All hardware, data, operational support and such other material and services determined to be necessary shall be released to test activities or otherwise delivered in accordance with the Manned Spacecraft Center approved program.

4.4.2 Hardware List.- Commensurate with program requirements and lead times involved, the Contractor shall prepare and furnish a complete list of all deliverable hardware covered by this Statement of Work including a list of spares, a list of all hardware to be GFE, and a list of all Government Furnished Property (GFP) support items. A brief justification for each hardware item requirement and the delivery date(s) thereof shall be included.

4.4.3 Hardware Deliveries.- The deliverable hardware shall include the mockup, test article and operational Lunar Excursion Modules, GSE spares, and materials as may be required for the Apollo program.

4.4.4 Mockups.- The mockups to be provided by the Contractor shall include but not be limited to the following:

Complete Lunar Excursion Module

Cabin interior arrangement

Cabin exterior equipment

Docking system

Environmental control system

Crew support system

Antenna radiation pattern

Handling and transportation

Module interface

4.5 Documentation

4.5.1 General.- The Contractor shall provide the documentation described in the following paragraphs in accordance with the delivery schedules, type classifications, and quantities listed in Table II. All documentation required shall be classified as one of three types. Type I documentation shall be submitted to the MSC for approval. Type II documentation shall not require approval but shall be submitted for coordination, surveillance, and/or information. Type III documentation shall be retained by the Contractor and made available to authorized representatives of the NASA for review, upon request. The preparation of Type I documentation by the Contractor shall be conducted in close coordination with the NASA. Implementation of Type I documentation shall not proceed until after approval by NASA or until 20 days after submitted, whichever is earlier.

4.5.1.1 Submission.- The Contractor shall submit all data and documentation to the MSC Apollo Spacecraft Project Office. Other simultaneous parallel paths of distribution shall be as specified by the MSC Apollo Spacecraft Project Office. All distributions shall be subject to prior MSC Apollo Spacecraft Project Office approval.

4.5.1.2 Document Revision.- The Contractor shall prepare and submit a method of document revision which will provide the MSC Apollo Spacecraft Project Office and other designated document recipients with the most current documentation as practicable.

4.5.2 Specifications

4.5.2.1 General.- The Contractor shall prepare the specifications indicated in the following paragraphs.

4.5.2.1.1 Ground Support Equipment Performance and Interface Specifications.- These specifications shall specify the function, performance, and interface requirements of the Lunar Excursion Module GSE and include qualification, reliability, and acceptance requirements.

4.5.2.1.2 Lunar Excursion Module Subsystem Specifications.- The Contractor shall prepare subsystem and other equipment specifications which define the function, performance, and configuration, and include qualification, reliability and acceptance requirements for the equipment which he furnishes.

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4.5.2.1.3 Material, Parts, and Process Specifications.- The Contractor shall provide all material, parts, and process specifications which are used during the project. In cases where adequate materials and parts specifications do not exist, or are not suitable for the intended use, procurement specifications will be prepared by the Contractor. Where standards and process specifications covering items such as cleaning, forming, heat treatment, etc., are not available or are not adequate, process specifications will be prepared by the Contractor. Materials specifications shall include requirements relative to toxicity and fire hazards under environmental extremes.

4.5.2.1.4 Mockup Specifications.- The Contractor shall prepare a mockup specification for each mockup specified in this Statement of Work or as may be required. These specifications shall be submitted to NASA for approval prior to the start of mockup fabrication.

4.5.2.1.5 Training Equipment Specifications.- Training equipment specifications shall be prepared by the Contractor in coordination with NASA. A separate specification shall be prepared for each new piece of equipment and each equipment modification.

4.5.2.1.6 Final Specifications.- The Contractor shall furnish one complete set of reproducible procurement specifications for each Contractor furnished system under this contract. Specifications shall be suitable for use in the procurement of any future systems.

4.5.3 Program Plans and Reports

4.5.3.1 Planning Reports.- The Contractor shall prepare and submit the program planning reports specified in Paragraph 4.3.2. The Contractor shall be responsible for maintenance of these plans through a revision system he will develop. All revisions shall be made with MSC Apollo Spacecraft Project Office approval. The program planning reports shall consist of the following documents:

4.5.3.1.1 Program Plan

4.5.3.1.2 Facilities Plan

4.5.3.1.3 Test Plan

4.5.3.1.4 Manufacturing Plan

[redacted]

4.5.3.1.5 Reliability Plan

4.5.3.1.6 Quality Program Plan

4.5.3.1.7 Maintenance Plan

4.5.3.1.8 Support Plan

4.5.3.1.9 Training Plan

4.5.3.1.10 End Item Test Plan

4.5.3.2 PERT Reports. - PERT reports shall be submitted in accordance with the NASA PERT Handbook.

4.5.3.2.1 The Contractor shall submit a PERT Event and Activities Description Document as specified in Paragraph 4.3.3.3.

4.5.3.3 Monthly Financial Management Report. - This report shall consist of a monthly cost report in accordance with Paragraph 4.3.5.

4.5.3.4 Hardware List. - The Contractor shall prepare and submit a list of all deliverable hardware items in accordance with Paragraph 4.4.2.

4.5.3.5 Mockup Inspection Plan. - The Contractor shall prepare and submit a mockup inspection plan.

4.5.3.6 Interface Documents. - The Contractor shall prepare and submit interface documents in accordance with Paragraph 4.2.5.

4.5.4 Progress and Status Reports

4.5.4.1 Monthly Progress Reports. - The Contractor shall submit monthly progress reports of all work accomplished during each month of Contract performance. For those months where a quarterly progress report is required, the report of monthly progress shall be included in the quarterly report. The monthly progress report shall cover the status of the development of the Lunar Excursion Module including management and major technical aspects, facilities and other similar items. A quantitative description of over-all progress, an indication of current problems which may impede progress and the proposed corrective action, and a discussion of the work to be performed during the next monthly reporting period shall be included.

4.5.4.2 Quarterly Progress Reports. - This report shall cover progress and status of the development of the Lunar Excursion Module including management and major technical aspects, facilities, and other similar items but excluding costs, for the preceding quarter. Major problems encountered and the solutions undertaken, or planned, shall be included. Any situation requiring MSC action or assistance shall be highlighted. Progress and status in relation to the master phasing and milestone schedules and any actual or anticipated changes thereto shall be shown, either by charts or by data sufficient to show this information on the charts previously submitted. In addition to factual data, these reports shall include a separate analysis section which interprets the results obtained, recommends further action, and relates occurrences to the ultimate objectives of the contract work. Sufficient diagrams, sketches, curves, photographs and drawings shall be included to convey the intended meaning.

4.5.4.3 Final Report.- The Contractor shall submit a final report which documents and summarizes the results of the entire contract work, including recommendations and conclusions based on the experience and results obtained. The final report shall include tables, drafts, diagrams, curves, sketches, photographs and drawings in sufficient detail to comprehensively explain the results achieved under the contract.

4.5.4.4 Weekly Launch Site Activities Reports.- This report shall cover the status of the launch site activities relative to the Lunar Excursion Module.

4.5.4.5 Monthly Weight and Balance Reports.- The Contractor shall prepare weight and balance reports which provide continuous weight and balance information for all Lunar Excursion Module Equipment including continuing weight trend information.

4.5.4.6 Emergency Action Reports.- These reports shall be used by the Contractor for reporting any urgent matters which, unless solved immediately, could cause serious program delay. Such reports shall be forwarded by the most expeditious means available. Such urgent matters shall include:

Strikes

Shortages of material and equipment in critical areas

Transportation tie-ups

Safety of flight problems

Critical development problems

Factors outside the Contractor's responsibility.

4.5.4.7 Quarterly Reliability Status Report.- The Contractor shall prepare reliability status reports which provide a comprehensive review of the reliability program including the current demonstrated reliability level for each major element and component, as defined in the reliability program plan; a discussion of reliability problems; failure analyses; and results of corrective action taken and corrective actions proposed. The Contractor shall propose recommendations for redesign, tradeoffs, etc., as a result of the analysis.

4.5.4.8 Still Photographs.- The Contractor shall provide still photographs in accordance with the detailed instructions and requirements of Appendix B.

4.5.4.9 Motion Picture Photography.- The Contractor shall provide 16-mm motion picture coverage in accordance with the detailed instructions and requirements of Appendix B.

4.5.4.10 Lunar Excursion Module Flight Reports.- A report showing the results of each flight test shall be submitted. Each such report shall consist of a detailed evaluation of the particular flight test and shall include the following types of information.

4.5.4.10.1 A section on the performance of each Lunar Excursion Module subsystem together with an analysis of any Lunar Excursion Module malfunctions and the probable cause of the subject malfunction.

4.5.4.10.2 A section devoted to unexpected significant Lunar Excursion Module difficulties, or results which are encountered during launch preparation, their bearing on future tests, and any corrective measures on product improvement proposed.

4.5.4.11 Lunar Excursion Module Equipment Status Report.- This report shall present a list of all Lunar Excursion Module equipment indicating pertinent characteristics, qualification status, required qualification status, usage, reuseability, importance to mission, and flight performance on each part.

4.5.4.12 Program Management Plan Reports.- The Contractor shall prepare Program Management Plan Reports which present milestones and schedule dates for each subsystem and each major area of Contractor effort. The milestones shall be selected such that at le st one shall be scheduled for completion each month. The number of milestones presented for each subsystem or major area shall be at least 25 per year, but not more than 100. Milestones for the first year shall be detailed but those for the balance of the project may be limited to major actions.

4.5.5 Non-Scheduled Reports and Data

4.5.5.1 Technical Data, Reports, and Analyses.- The Contractor shall prepare technical reports which describe the studies, analyses, and results of the contractual effort. The reports shall be prepared at times when complete blocks of work have been accomplished and, if appropriate, as logical subdivisions thereof. Major technical areas shall not be combined in a single document, but shall be published individually. The individual reports shall cover such technical specialties as stress analyses, reliability analyses, failure mode analyses, etc.

4.5.5.2 Design Information.- The Contractor shall establish a method of submitting and shall submit periodically, preliminary design information before finalization of design to assist in expediting the interchange of design data and to keep MSC technical design groups continually and currently appraised of the Contractor's activities, philosophy, approaches, solutions and design evaluations of all phases and facets of design. This procedure will allow MSC technical personnel the prerogative to comment before all design features are finalized and will tend to expedite the final approval of Type I documentation.

4.5.5.3 Materials Reports.- These reports shall be submitted in accordance with the clause contained in the contract schedule entitled, "Materials Reports."

4.5.6 Qualification Reports and Data

4.5.6.1 Qualification Status List.- The Contractor shall provide a Qualification Status List in accordance with the provisions of paragraph 4.3.5 of Reference 1.

4.5.6.2 Qualification Test Reports and Data. - Data showing the results of all qualification tests shall be maintained and indexed in a master file by the Contractor. Reports shall be forwarded to the NASA Apollo Spacecraft Project Office showing the results of all qualification tests.

4.5.6.3 Failure Data. - The Contractor shall prepare failure reports on all failures which occur on Contractor furnished and Government Furnished Equipment during all phases of testing, operation, etc.

4.5.6.4 Monthly Failure Summary. - The Contractor shall prepare a monthly failure summary which summarizes the failure reports prepared above. Each succeeding summary shall incorporate those preceeding and shall include detailed trend analysis. They shall indicate fixes incorporated as a result of failures and the trend expected after these fixes.

4.5.7 Quality Program Reports

4.5.7.1 Acceptance Test Data Sheets. - Copies of data sheets showing the results of acceptance tests performed by the Contractor on major end items of Ground Support Equipment and on major components of the Lunar Excursion Module shall be prepared and furnished for review by the NASA Manned Spacecraft Center. Acceptance test data on all other items shall be maintained by the Contractor and shall be made available for review by representatives of the NASA Manned Spacecraft Center upon request.

4.5.7.2 Data and Reports on Other Tests. - Data showing the results of all required tests not otherwise provided for herein, which are the responsibility of the Contractor, shall be recorded and maintained on file. Reports shall be submitted on each of these tests or test series.

4.5.7.3 Special Sampling Plans. - The Contractor shall provide special sampling plans (defined as those other than military standard sampling plans) in accordance with the provisions of Paragraph 12.3 of Reference 1.

4.5.7.4 Results of Special Measuring and Test Equipment Evaluations.- The Contractor shall provide results of special measuring and test equipment evaluations in accordance with the provisions of Paragraph 9.4 of Reference 1.

4.5.7.5 Monthly Quality Status Report. - The Contractor shall provide a Monthly Qualitv Status Report in accordance with the provisions of Paragraph 14.2 of Reference 1.

4.5.7.6 Quarterly Summaries of Quality Program Performance Audits. - The Contractor shall provide quarterly summaries of quality program performance audits in accordance with the provisions of Paragraph 15.2 of Reference 1.

4.5.7.7 Test and Inspection. - The Contractor shall provide inspection and test procedures in accordance with the provisions of Paragraph 7.3.1 of Reference 1.

4.5.7.8 End Item Test and Inspection Procedures. - The Contractor shall provide end item test and inspection procedures in accordance with the provisions of Paragraph 7.4.2.2 of Reference 1.

4.5.7.9 Process Control Procedures. - The Contractor shall provide process control procedures in accordance with provisions of Paragraph 7.5.4 of Reference 1.

4.5.7.10 Storage Procedures for End Items. - The Contractor shall provide storage procedures for end items in accordance with the provision of Paragraph 11.5 of Reference 1.

4.5.7.11 Application of Sampling Plans. - The Contractor shall provide details of the application of sampling plans in accordance with the provisions of Paragraph 12.3 of Reference 1.

4.5.8 Drawings. - Drawings, layouts of various major assemblies, inboard profiles, etc., required by the NASA for coordination, technical monitoring, and/or information shall be furnished to autorized representatives of the NASA upon request both prior to and subsequent to release.

4.5.8.1 Maintenance of Drawings. - The Contractor shall submit a complete up-to-date set of Contractor and Subcontractor drawings sufficient to describe each of the equipments for which he is responsible. These drawings shall be prepared using the Contractor's internal drawing system and shall conform to high quality commercial standards.

4.5.8.2 Final Drawing Submission. - The Contractor shall submit on microfilm a set of engineering drawings sufficient to enable manufacture of any equipment or items furnished under the contract (other than components or items of standard commercial design or items fabricated heretofore); and a set of flow sheets or engineering drawings sufficient to enable performance of any process developed under the contract.

4.5.8.3 Drawing Approval.- Approval of Contractor's drawings will be general and will not relieve the Contractor from the responsibility for the correctness of the drawings furnished by him, nor for their compliance with the specifications, nor for proper fitting and construction of the work, nor for furnishing materials and work required by the contract which may not be indicated on the drawings when approved. The approval of the Contractor's drawings shall not be construed as approving changes in scope of the contract.

4.5.8.4 Drawing List.- The Contractor shall prepare a drawing list which presents all assigned drawing numbers, titles, release dates, effectivities, next assembly numbers, and next assembly titles. It shall include a brief description of each drawing. Periodic revisions shall reflect additions and deletions.

4.5.9 Support Manuals.- The Contractor shall prepare and provide manuals to define, in detail, operating instructions as well as maintenance, check-out, and test procedures as indicated in the following paragraphs. The instructions and procedures contained in the manuals shall be arranged to permit operation, maintenance, check-out or test of the equipment covered by the appropriate manual in the minimum feasible amount of time. The material shall be designed to be readily understood by the personnel who will operate and/or maintain the equipment.

4.5.9.1 Check-out Manuals.- The check-out manuals shall provide the procedure and information required to perform check-out tests of the appropriate systems. They shall permit complete check-out in the maintenance area or launch site.

4.5.9.2 Lunar Excursion Module Operations Manuals.- Lunar Excursion Module operations manuals shall define the detailed procedures required to perform the tasks directly associated with the Lunar Excursion Module prior to, including, and subsequent to launch. The manuals shall present, in sequential order, the instructions for tasks performed by members of the team who participate in Lunar Excursion Module operations.

4.5.9.3 Lunar Excursion Module Flight Operations Manual.- This operation manual shall provide the instructions and procedures to be followed by the crew involving the Lunar Excursion Module. The tasks to be performed by the crew shall be presented in a logical sequence in individual sections pertinent to each phase of the mission.

4.5.9.4 Maintenance and Repair Manuals.- These manuals shall provide complete instructions and procedures for the maintenance and repair of the Lunar Excursion Module and associated Ground Support Equipment. A manual shall be provided for each major item of equipment or subsystem.

4.5.9.5 Lunar Excursion Module Familiarization Manual.- The familiarization manual shall provide a description of the complete Lunar Excursion Module. Each operational system shall be described in general terms but with sufficient detail to convey a clear understanding of the system as a whole. This manual shall cover the general operational procedures and include a reference index of all support manuals. This manual shall serve as an orientation-indoctrination type document and as a reference document containing information relative to all systems and major components.

4.5.9.6 Ground Support Equipment Manuals.- A manual shall be provided for each major item of Ground Support Equipment. These manuals shall contain all the procedural instructions directly associated with, and required for, operation and check-out of the ground support equipment.

4.5.9.7 Description Manuals.- A Description Manual shall be prepared for each Lunar Excursion Module intended for flight and shall provide a description of the complete module and associated GSE. Each operational system shall be described in sufficient detail to indicate its operating characteristics and limitations. Deviations of detail design or operation from that which is established as standard for "protection" items should be specifically identified. The manuals will serve as a series of documents that establish the exact configuration of each module and its associated GSE. Timely revision and updating of each manual shall be provided for.

4.5.9.8 Transportation and Handling Manuals. - These manuals shall provide the procedures and special requirements for transportation, handling, and storage of the Lunar Excursion Module and major items of GSE.

4.5.9.9 Training Manuals. - The Contractor shall provide training manuals for the NASA conducted flight crew and ground crew training programs associated with the training equipment supplied by the Contractor. Each trainer or part trainer supplied by the Contractor shall be provided with a maintenance manual giving complete instruction for repair and maintenance of the equipment and an instructor's manual which shall include operating instructions and a recommended syllabus for the use of the trainer. A flight operational training manual (s) shall be provided suitable for use in the combined flight crew and flight monitor training. This manual shall describe operational characteristics of the equipment in terms of the displays available to the flight crew and ground crew. It shall describe the major types of malfunctions and how they may be isolated by ground and flight crews. A recommended syllabus for flight monitor-flight crew combined exercises shall be provided.

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APPENDIX A

TECHNICAL APPROACH

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1.0 INTRODUCTION.- The Technical Approach Appendix presents a technical description of the operational and flight plans and systems approach for the Apollo Spacecraft. The description constitutes a technical framework within which the initial design and operational modes of the Spacecraft are to be further developed.

The Apollo Spacecraft, operational concepts and flight plans described herein are defined by the requirements of the ultimate mission, manned lunar landing and return. The resulting basic systems are then considered to be off-loaded for intermediate missions and qualification flights.

Since the Technical Approach Appendix applies to the entire Apollo Spacecraft, only certain paragraphs will have direct requirements on the development of the Lunar Excursion Module. For example, paragraph 4.3 describes the characteristics of the major systems of the Lunar Excursion Module. It is felt that the assembly of all pertinent technical data to the development of the Apollo Spacecraft in one document will lead to a better understanding between various Apollo contractors and result in more compatible modules.

2.0 PROJECT IMPLEMENTATION CRITERIA.- Considerations which determine the design of the Apollo Spacecraft, its operation, and ground support activity are presented in this section.

2.1 Technical Guidelines.- The Technical Guidelines are the collection of principles to which the basic technical approach of the Space Vehicle System must be responsive. They are the first order criteria from which successive design criteria, performance margins, tolerances, and environments are developed.

2.1.1 Space Vehicle Concept

2.1.1.1 Launch Vehicle.- The Saturn C-5 Launch Vehicle shall be the basic launch vehicle for lunar missions. Earlier phases will employ other Saturn Launch Vehicles, and other launch vehicles may be used for certain development and qualification flights.

2.1.1.2 Spacecraft.- The Spacecraft shall be composed of separable modules such that (1) "effective weight" principles can be realized through proper jettisoning of expendable units, (2) performance benefits can be obtained by utilizing staging techniques and (3) module configurations peculiar to specific missions can be modified without substantial effect upon modules common to general missions. The general features of the Spacecraft are described in the following paragraphs.

2.1.1.2.1 Command Module.- The Spacecraft shall include a recoverable Command Module which shall remain essentially unchanged for all Apollo missions. This module where practical shall contain the communication, navigation, guidance, control, computing, display equipment, etc., requiring crew mode selection. In addition, other equipment required during nominal and/or emergency earth landing phases shall be included in the Command Module. This module shall include features which allow effective crew participation such as windows with a broad field of view for general observation, earth landing, rendezvous and docking. Equipment arrangements shall allow access for maintenance both prior to and subsequent to earth launch. The Command Module shall provide for sufficient storage of experimental measurements obtained during flight to satisfy mission objectives.

2.1.1.2.1.1 Housing.- The Command Module shall house the three crew members during launch, translunar, transearth and reentry phases. While the Lunar Excursion Module is separated from the Command Module for performing the lunar landing and return, the Command Module will house one crew member.

2.1.1.2.1.2 Reentry and Earth Landing.- The Command Module shall be the reentry and earth landing vehicle for both nominal and emergency mission phases. The use of equipment such as ejection seats or personal parachutes is not precluded for certain cases.

2.1.1.2.1.3 Ingress and Egress.- Ingress and egress hatches to the Command Module shall not be obstructed at any stage of space vehicle countdown, flight, and recovery. Means of egress to free space without decompression of the entire Command Module shall be provided.

2.1.1.2.2 Service Module.- The Spacecraft shall include an unmanned Service Module which shall contain stores and systems which do not require crew maintenance or direct operation, and which are not required by the Command Module after separation from the Service Module. The Service Module shall house all propulsion systems except that required for lunar descent, landing, and launch and attitude control during reentry. The Service Module Propulsion System shall provide on a backup basis the propulsion required to successfully complete the rendezvous and docking maneuvers with the Lunar Excursion Module. Consideration shall be given to inflight maintenance of equipment in the Service Module by crewmen in space suits. The Service Module may be modified in accordance with particular mission requirements, but the principal structural load paths, geometric arrangement, and configuration shall remain unchanged for various missions and project phases. It is expected that the Service Module would normally be jettisoned prior to reentry into the earth's atmosphere. The Service Module shall not be recoverable.

2.1.1.2.3 Lunar Excursion Module.- The Spacecraft shall include a Lunar Excursion Module which will serve as a vehicle for carrying two of the crew members and payload from the Spacecraft in a lunar orbit to the lunar surface and back. This module shall have the capability of performing the separation, lunar descent, landing, ascent

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rendezvous, and docking independent of the Spacecraft. The Lunar Excursion Module will allow for crew exploration in the vicinity of the lunar touchdown. This module is not required to have lunar surface mobility. The Lunar Excursion Module shall contain the communication, navigation, guidance, control, computing, display equipment, etc., requiring crew mode selection. This module shall include features which will allow effective crew participation such as windows with a broad field of view for general observation, lunar descent, landing, ascent, rendezvous, and docking. Equipment arrangements shall allow access for maintenance both prior to and subsequent to earth launch. The Lunar Excursion Module shall not be recoverable.

2.1.1.2.3.1 Housing.- The Lunar Excursion Module shall house two crew members during separation, lunar descent, landing, ascent, rendezvous, and docking. It shall also provide sufficient storage of experimental measurements to satisfy mission objectives.

2.1.1.2.3.2 Ingress and Egress.- A hatch shall be provided in the Lunar Excursion Module such that the crew members can transfer between the Lunar Excursion Module and Command Module in a docked configuration without being exposed to the environment of space. Another hatch shall be provided to allow ingress and egress to the Lunar Excursion Module during countdown and allow egress into space while in the docked position.

2.1.1.2.3.3 Propulsion.- The Lunar Excursion Module shall house all propulsion systems required for separation from the Command Module, lunar descent, landing, ascent, rendezvous, and docking.

2.1.1.2.3.4 Equipment.- The Lunar Excursion Module shall have an equipment area for housing stores and systems which do not require crew maintenance or direct operation. Consideration shall be given to part of the equipment being jettisoned while on the lunar surface. Consideration shall be given to inflight and lunar maintenance of equipment in the equipment area by crewmen in space suits.

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2.1.1.2.4 Spacecraft Adapter.- The Spacecraft Adapter shall structurally and functionally adapt the Service Module to the Launch Vehicle for non-lunar landing and lunar landing configurations.

2.1.2 Operational Concept

2.1.2.1 Manning of Flights. - The Spacecraft shall be designed for manned operation with full utilization of human crew capabilities to increase reliability in terms of both flight safety and mission success. Automatic systems will be employed where they will enhance the performance of the mission. Where unmanned development flights are required, specially equipped Spacecraft may be used.

2.1.2.2 Onboard Command. - The Spacecraft shall have the capability to perform the mission independent of ground based information and command. This statement shall not preclude the use of ground based information to increase reliability, accuracy, and performance. The Lunar Excursion Module shall have the capability to perform its phase of the mission independent of the Command Module and ground based information and command. This statement shall not preclude the use of Command Module and ground based information to increase crew safety, reliability, accuracy, and performance.

2.1.2.3 Flight Crew. - The Spacecraft flight crew shall consist of three men. The flight crew for the Lunar Excursion Module operation shall consist of two of the three Spacecraft crew members. The third crew member remains in the Command Module in lunar orbit.

2.1.2.3.1 Crew Participation. - The flight crew shall have the capability to direct the control of the Spacecraft throughout all flight modes. The flight crew shall participate in navigation, control, monitoring, computing, repair, maintenance, and scientific observation when such participation enhances mission reliability or crew safety. Status of systems shall be displayed for crew monitoring, failure detection, and operational mode selection including Spacecraft and Launch Vehicle systems status, staging, sequences, and touchdown control. The Spacecraft shall be designed so that any single crewman will be able to perform all tasks essential to return the Command Module. The Lunar Excursion Module shall be designed so that any single crewman will be able to perform all tasks essential to return the Lunar Excursion Module to the Command Module and successfully perform the rendezvous and docking maneuver.

2.1.2.3.2 Crew Mobility. - A considerable degree of crew mobility is required. Towards this end, a "shirtsleeve" environment shall be provided in the Command Module during all flight phases. The crew of the Lunar Excursion Module will wear unpressurized space suits during normal operation.

2.1.2.3.3 Automatic Systems. - Automatic systems shall be employed in the Spacecraft to enhance its performance, i.e., to obtain precision, speed of response, or to relieve the crew of tedious tasks. The degree of automaticity will be determined by optimization of mission reliability. Crew monitoring of these systems with provision for exercising command control and/or mode selection is required. (During the initial phase of the contract the Lunar Excursion Module Associate Contractor in conjunction with the Navigation and Guidance Associate Contractor, shall conduct studies comparing Lunar Excursion Module designs that would be capable of unmanned lunar landing, take-off, rendezvous, and docking with designs in which the crew would play an essential roll. A decision regarding the requirement or lack thereof for unmanned mission capability will be made by NASA subsequent to these studies).

2.1.2.3.4 Abort Initiation. - Provisions shall be made for crew initiation of all abort modes. Initiation of abort modes by ground command or automatic systems shall be provided when this enhances crew safety.

2.1.2.4 Flight Time Capabilities

2.1.2.4.1 Flight. - The Command and Service Module systems shall be capable of performing at their nominal design performance level for a mission of 14 days without resupply. For lunar landing missions, 7 of the 14 days may be in lunar orbit. The Lunar Excursion Module systems shall be capable of performing at their nominal design performance level for a mission of two days without resupply. Consideration should be given to extending this capability to 7 days employing a supply module or resupply vehicle.

2.1.2.4.2 Post Flight. - The Command Module shall provide the crew a habitable environment for one day and a survivable environment for one week following a land or water landing.

2.1.2.5 Earth Landing.- The Spacecraft shall have the capability of initiating a return and earth-landing maneuver at any time during either lunar or orbital missions. Prior to each flight, a primary ground landing site and suitable backup landing site will be selected for normal mission landing. Additional criteria apply as follows:

2.1.2.5.1 Lunar Missions.- Alternate earth landing sites shall be designated prior to flight such that a landing is possible at these sites regardless of the time of reentry.

2.1.2.5.2 Earth Orbital Mission.- The Spacecraft shall be capable of landing at the primary landing site (or at the backup site) from at least three orbits per day. In addition, alternate sites which may involve either land or water landing will be designated such that at least one alternate site can be reached for a landing from each orbit.

2.1.2.6 Lunar Landing.- The Lunar Excursion Module shall have the capability of landing within one-half a mile of certain designated near equatorial locations.

2.1.2.7 Ground Monitoring and Communication

2.1.2.7.1 Earth Orbital Missions

2.1.2.7.1.1 Power Flight.- There shall be continuous monitoring of onboard system and crew status during powered flight.

2.1.2.7.1.2 Orbital Flight.- Flight progress, onboard systems operation, and crew status shall be monitored by the Ground Operational Support System a minimum of one contact with the Spacecraft per hour.

2.1.2.7.2 Lunar Missions.- Ground tracking shall be provided throughout the lunar mission for the period between leaving the earth parking orbit and the initiation of earth reentry except where limited by the Spacecraft being blanketed by the moon. The Spacecraft shall be designed to permit the Lunar Excursion Module, Command Module, and earth stations to communicate directly with one another, except when shielded by the moon in which case advantage may be taken of relay capabilities.

When the Spacecraft is on the far side of the moon, consideration should be given to the possibility of storing on tape, telemetry data and voice to be played back upon emerging from moon shielding.

2.1.2.8 <u>Apollo Mission Control Center</u>.- All phases of the Apollo missions shall be directed from the Apollo Mission Control Center. All mission communications during Apollo missions shall be controlled by the Apollo Mission Control Center.

2.1.2.9 <u>Tracking and Ground Instrumentation Network</u>.- All existing networks and associated facilities shall be considered for support of an Apollo mission where practical.

2.1.3 Reliability and Crew Safety.- The Apollo program requires the concentration of a major effort in the area of reliability. This is partly dictated by the nature of the mission and the larger size and cost of the individual vehicles; but primarily by the requirement for safety of the crew. The nature of the lunar landing mission requires that crew safety be achieved through overall reliability rather than through the use of escape systems. Therefore, the basic design of the Apollo Spacecraft must be based on the recognition of the fact that a very high degree of inherent reliability is an overriding requirement and a special effort must be made to realize the full inherent reliability during operation. Mission reliability and crew safety goals, assuming a launch vehicle reliability of 0.95 and including the effect of ground complex reliability, but excluding consideration of radiation and meteoroid impact, shall be as follows:

2.1.3.1 Mission Reliability.- The probability of accomplishing the mission objectives shall be 0.90. Of this overall reliability goal, the reliability goal apportioned to the Lunar Excursion Module shall be 0.984.

2.1.3.2 Crew Safety

2.1.3.2.1 Nominal.- The probability that none of the crewmen shall have been subjected to conditions greater than the nominal limits specified in the crew requirements section shall be 0.90.

2.1.3.2.2 Emergency.- The probability that none of the crewmen shall have been subjected to conditions greater than the emergency limits specified in the crew requirements section shall be 0.999. Of this overall crew safety goal, the crew safety goal apportioned to the Lunar Excursion Module shall be 0.9995.

2.2 Design Criteria.- Design and operational procedures shall be conducted in accordance with rational design principles to include but not be limited to the following:

2.2.1 Reliability.- Attainment of the maximum mission reliability and crew safety shall be the most important single consideration in the design, construction, handling, and operation of the Spacecraft.

2.2.2 Limit Conditions.- The design limit load envelopes shall be established by superposition of rationally deduced critical loads for all flight modes. Load envelopes shall recognize the cumulative effects of additive type loads. No system shall be designed incapable of functioning at limit load conditions.

2.2.3 Performance Margins.- Rational margins shall be apportioned to systems and components such that the greatest overall design efficiency is achieved within the Launch Vehicle capabilities and implementation criteria constraints. The following specific systems margins are derived from rational consideration of past and anticipated operational experience. They are to be used as design criteria until experience justifies modification.

2.2.3.1 Multiple Failure.- The decision to design for single or multiple failures shall be based on the expected frequency of occurrence as it affects system reliability and safety.

2.2.3.2 Fail Safe.- System or component failure shall not propagate sequentially, i.e., design shall "fail safe".

2.2.3.3 Design Margins.- All Spacecraft systems shall be designed to positive margins of safety.

2.2.4 Performance Criteria

2.2.4.1 Repressurization

2.2.4.1.1 Command Module.- The repressurization system shall be designed for two complete cabin repressurizations, a minimum of 18 airlock operations, and a continuous leak rate as high as 0.2 lbs. per hour. Normal operating time of the portable life support system without resupply is four hours. Provisions shall be made for a total of six recharges.

2.2.4.1.2 Lunar Excursion Module.- The repressurization system shall be designed for 6 complete cabin repressurizations, and a continuous leak rate as high as 0.2 lbs. per hour. Provisions shall be made for a total of 6 recharges of the portable life support systems.

2.2.4.2 Vacuum Operation of Cabin Equipment

2.2.4.2.1 Command Module.- Equipment which is normally operated in the pressurized cabin environment shall be designed to function for a minimum of four days in vacuum without failure.

2.2.4.2.2 Lunar Excursion Module.- Equipment which is normally operated in the pressurized cabin environment shall be designed to function for a minimum of two days in vacuum without failure. Time period in vacuum prior to operation shall be a minimum of 4 days.

2.2.4.3 Advances in Technology.- Flexibility shall be incorporated into the design such that advantage can be taken of advances in technology.

2.2.4.4 Command Module Reuse.- The Command Module and internal systems shall be designed for repeated mission reuse after recovery. The internal systems shall be designed for an operational life of three nominal missions. Exceptions are made for systems and components normally classified as expendable and those flight items which would be unduly compromised in design by environmental conditions occurring after their operational function has been performed.

2.2.4.5 Command Module Water Stability.- Command Module flotation and water stability characteristics shall be such as to ensure that the Command Module will recover from any initial attitude and will float upright with normal egress hatches clear of the water. Command Module seakeeping capability shall be such as to ensure a 7 day flotation period.

2.2.5 Spacecraft

2.2.5.1 General

2.2.5.1.1 Thermal Resistance.- The Spacecraft modules shall be designed such that additional or lesser requirements in thermal resistance may be accommodated or taken advantage of without major overall design changes.

2.2.5.1.2 Meteroid Protection.- The Spacecraft modules shall be designed such that additional or lesser requirements in meteroid protection may be accommodated or taken advantage of without major overall design changes.

2.2.5.1.3 Radiation Shielding.- The Spacecraft modules shall be designed such that additional or lesser requirements in radiation protection may be accommodated or taken advantage of without major overall design changes.

2.2.5.1.4 Isolation of Modifications.- The Spacecraft modules and systems shall be designed such that general modifications to one module or its systems do not propagate through the other modules.

2.2.5.1.5 Spacecraft Maintenance.- Equipment arrangements, accessibility, and interchangeability features that allow efficient preflight and inflight servicing and maintenance shall be given full consideration. The use of automatic checkout equipment shall not preclude manual entrance into and checkout of the system being checked. Design considerations shall also include efficient mission scrub and recycle procedures.

2.2.5.1.6 Ground Handling.- Full design recognition shall be given to the durability requirements of Spacecraft equipment and systems subjected to the continuous handling and "wear-and-tear" of preflight preparation.

2.2.5.2 Structural Systems

2.2.5.2.1 Design Factors

2.2.5.2.1.1 Ultimate Factor.- The ultimate factor shall be 1.5 applied to limit loads. This factor may be reduced to 1.35 for special cases upon rational analysis and negotiation with Manned Spacecraft Center.

2.2.5.2.1.2 Pressure Vessel Design Factors.- Pressure vessels are to be designed using the following factors based on limit loads.

2.2.5.2.1.2.1 Pressure Vessel Proof Factor.- The proof factor shall be 1.33 when pressure is applied as a singular load. This factor may be reduced for special cases upon rational analysis and negotiation with Manned Spacecraft Center.

2.2.5.2.1.2.2 Pressure Vessel Ultimate Factors.- The ultimate factor shall be 2.00 when pressure is applied as a singular load. This factor may be reduced to 1.5 for special cases upon rational analysis and negotiation with Manned Spacecraft Center. The main propellant tanks are a special case and will have an ultimate factor of 1.5.

2.2.5.2.1.2.3 Pressure Vessel Limit Loads.- Limit loads shall be obtained with limit pressures. When pressure effects are relieving, pressure should not be used.

2.2.5.2.1.2.4 Pressure Stabilized Structures.- No primary structures shall require pressure stabilization.

2.2.5.3 Flight Loads

2.2.5.3.1 Tumbling at Maximum Dynamic Pressure.- Primary Command Module structures are to be designed for loads arising from a "tumbling" of the escape vehicle at maximum dynamic pressure during launch.

2.2.5.3.2 20g Reentry.- Primary Command Module structures are to be designed for a limit load of 20g during reentry.

2.2.5.3.3 Noise.- The design shall accommodate sound pressure levels of 166 db in the frequency range 4 to 9600 cps emanating from the Launch Escape System during both launch and abort modes.

2.2.5.3.4 Buffet.- The design shall accommodate a buffet pressure of 1.5 psi (rms) in the frequency range of 0 to 4 cps on the Service Module and Adapter during the earth-launch phases.

2.2.5.3.5 Vibration.- The application of propulsion system transients shall consider the engines to be deflected in the worst manner within allowable gimble limits. The effects of the steady and transient inputs shall be combined. The vibration analyses shall recognize the lower damping present in a vacuum.

2.2.5.3.6 Dynamic Loading.- The calculation of dynamic loads shall include the effects of engine start, rebound on the pad, lift off transients including ground winds, gusts, wind shears, buffeting.

2.2.5.3.7 Separation, Maneuvering, and Docking.- Separation, maneuvering, and docking loads associated with Command Module attachment to and disengagement from the Lunar Excursion Module shall be considered.

2.2.5.3.7.1 Separation.- Separation shall not be impaired by reasonable tolerances on symmetry and/or simultaneity of thrust pulses of reaction nozzles. All disconnect mechanisms shall avoid release of parts which may pierce or inflict damage to vital components.

2.2.5.3.7.2 Maneuvering.- The loads shall reflect the response of the structure to the transient thrust forces.

2.2.5.3.7.3 Docking.- The loads and energy levels shall be defined by a dynamic analysis of the docking impact. This analysis shall also furnish load factors on crew equipment and structure. The worst combination of major design parameters shall be used for the analysis.

2.3 Nomenclature

2.3.1 Reference Axes. - The reference axes of the Spacecraft shall be orthogonal and identified as shown in Figure 1. The reference is to the crew members in their normal earth launch position in the Command Module. All of the modules shall use the same reference axes system.

2.3.1.1 X-Axis. - The X-Axis shall be paralled to the nominal launch axis of the Space Vehicle and be positive in the direction of initial flight.

2.3.1.2 Y-Axis. - The Y-Axis shall be normal to the X-Axis and positive to the right of a crewman when the crewman is facing towards positive X.

2.3.1.3 Z-Axis. - The Z-Axis shall be normal to both the X and Y axes and be positive in the direction of the crewman's feet.

2.4 Crew Requirements. - Design and operational procedures shall be in accordance with the crew requirements data presented here. The data presented are for various limits as defined below.

2.4.1 Nominal Limits. - Nominal limits are defined as the limits within which the crew's environment shall be maintained during normal operations.

2.4.1.1 Nonstressed Limits. - Nonstressed limits are defined as the environmental limits to which the crew may be subjected for extended periods of time such as orbit, lunar transit, and periods subsequent to normal landings.

2.4.2 Emergency Limits. - Emergency limits are defined as the environmental limits beyond which there is a high probability of permanent injury, death, or incapacity to such extent that the crew could not perform well enough to survive.

2.4.3 Metabolic Requirements. - The average daily metabolic requirements for each crew member are listed below.

Oxygen consumption	1.8 lb/day/man
Carbon dioxide output	2.3 lb/day/man
Heat output	11,300 BTU/day/man
Water consumption*	6.0 lb/day/man (This includes water in food; additional water may be required for sanitation.)
Food consumption	2800 Kcal/day/man

*Water consumption for the crew members while operating in the Lunar Excursion Module should be increased to 13.2 lb/day/man.

2.4.4 Crew Environment Requirements

2.4.4.1 Cabin Pressure. - The cabin pressure nominal limits shall be 3.5 psia minimum and 15.0 psia maximum. The emergency limit shall be 3.5 psia minimum.

2.4.4.2 Oxygen Partial Pressure. - The oxygen partial pressure nominal and emergency limits shall be 160 mm Hg minimum.

2.4.4.3 Carbon Dioxide Partial Pressure. - The carbon dioxide partial pressure nominal limit shall be 7.6 mm Hg maximum. The emergency limits are presented in figure 2.

2.4.4.4 Cabin Temperature. - The cabin temperature nonstressed limits shall be 70° F minimum and 80° F maximum. The stressed and emergency limits are presented in figures 3 and 4, respectively.

2.4.4.5 Cabin Relative Humidity. - The cabin relative humidity nonstressed limits shall be 40 percent minimum and 70 percent maximum. The stressed and emergency limits are presented in figures 3 and 4 respectively.

2.4.4.6 Radiation. - The nominal limit shall be the average yearly exposure tabulated in figure 5. The emergency dose limits shall be the maximum permissible, single acute emergency dose as tabulated in figure 5. Dosage calculations shall be based on the model presentation in figure 6. In the absence of sufficient information to assign dose value due to secondary radiation, a value of 50 percent of the primary dose will be used.

2.4.4.7 Noise. - The noise nonstressed limit shall be 80 db overall and 55 db in the 600 cps to 4800 cps range. The stressed limit shall be the maximum noise level which will permit communications with the ground and between crew members at all times. The emergency limit is presented in figure 7.

2.4.4.8 Vibration. - The vibration stressed, nonstressed, and emergency limits are presented in figure 8.

2.4.4.9 Sustained Acceleration. - The sustained acceleration limits for eyeballs out, down, and in conditions are presented in figures 9, 10, and 11. The limits presented were obtained from references 2 through 9, and are for currently available restraint systems, optimum body positioning, and without the use of G-suits. The sustained acceleration performance limits are defined as the maximum sustained acceleration to which the crew shall be subjected and still be required to make decisions, perform hand controller tasks requiring visual acuity, etc.

2.4.4.10 Impact Acceleration. - The impact acceleration nominal and emergency limits are presented in figures 12 and 13, respectively.

2.5 Natural Environment. - Design and operational procedures shall be in accordance with the natural-environment data presented here. It should be recognized that all natural environment data required for the project are not included herein.

2.5.1 Launch

2.5.1.1 Atmospheric Pressure, Density, and Temperature. - The surface variation of atmospheric pressure, density, and temperature is given in reference 10.

2.5.1.2 Wind. - The direction, magnitude, and cumulative percentage of surface winds are given in reference 11.

2.5.1.3 Precipitation. - The average monthly precipitation is given in figure 14.

2.5.1.4 Thunderstorms. - The average number of hours per month during which there are thunderstorms is shown in figure 15.

2.5.1.5 Surface Temperature. - The maximum, minimum, and average temperatures are given in figure 16.

2.5.2 Flight

2.5.2.1 Atmospheric Phase

2.5.2.1.1 Atmospheric Pressure, Density, and Temperature. - The altitude variation of atmospheric pressure, density, and temperature is given in reference 10.

2.5.2.1.2 Wind. - The variation of wind with altitude is given in reference 11.

2.5.2.2 Mission Phase

2.5.2.2.1 Solar Phenomena. - The hazards associated with an active sun are presented as a model solar event system with an indicated average frequency of occurrence.

2.5.2.2.1.1 Model Solar Event. - The time integrated model solar event is shown in figure 17. In arriving at this spectrum it is assumed that the flux of particles in energy range E to E + dE can be described by

[redacted]

$$\phi\,(E) = kt \qquad t<t_o$$

$$\phi\,(E) = k\left(\frac{t}{t_o}\right)^2 \qquad t>t_o$$

t_o (time of maximum flux) is related to energy by

$$E = e^{-.13t}$$

2.5.2.2.1.2 Probability of Encounter. - The probability of encounter of a solar event shall be assessed on the basis of total particles in the event. Figure 18 presents the average frequency for particles above 100 MEV over a seven-day mission. The total number of particles between 5 to 100 MEV range is shown in figure 17.

2.5.2.2.2 Van Allen Radiation Belts. - A description of the Van Allen radiation belts is presented in figure 19.

2.5.2.2.1 Inner Belt. - The inner belt is concentrated between the geomagnetic latitudes of 25 degrees North and 25 degrees South. It initiates as an altitude of 500 km and peaks in intensity at an altitude of 8500 km.

2.5.2.2.2.2 Outer Belt. - The outer belt is concentrated between the geomagnetic latitudes of 50 degrees North and 50 degrees South. It initiates at an altitude of 15,000 km, peaks in intensity at an altitude of 16,000 km, and decreases to a minimum intensity at an altitude of 21,000 km.

2.5.2.2.3 Meteroid Considerations. - The hazards involved in encountering meteroid will be assessed on sporadic activity only. The flux considerations for sporadic activity shall be based upon the Whipple distribution presented in figure 20.

2.5.2.2.4 Electromagnetic Radiation. - Electromagnetic radiation to be used for Spacecraft environmental analysis is presented in reference to its source.

2.5.2.2.4.1 Solar Radiation. - The electromagnetic radiation from the sun covering the spectrum from 60 angstroms to 1300 angstroms is given in figure 21 from 1300 angstroms to 2000 angstroms is given in figure 22 and from .2 microrns is given in figure 23.

[redacted]

2.5.2.2.4.2 Earth Radiation and Reflection.- The earth's albedo shall be considered as 35 percent. The remaining 65 percent shall be considered to be absorbed and some re-emitted as thermal radiation. The spectrum for the earth's albedo at local noon is given in figure 24. The radiation at the center of the dark side shall be considered to originate from a 251° K black body.

2.5.2.2.4.3 Lunar Surface Properties.- The physical characteristics of the lunar surface and topography shall be considered to be those given in reference 12.

2.5.2.2.4.4 Background Radiation.- The background radiation from celestial sources shall be considered to be 10^{-4} ergs/cm^2 sec in the interval 1230 to 1350 angstroms.

2.5.2.2.5 Interplanetary Atmosphere.- The interplanetary atmosphere shall be considered as shown in figure 25.

2.5.2.2.6 Space Background.- The space background electromagnetic radiation is presented above. The corpuscular radiation shall be considered as shown in figure 26 which represents the cosmic ray flux.

2.5.2.2.7 Earth Gravitational and Geometrical Constants.- The following earth gravitational and geometrical constants are to be used for tracking and orbital computations:

2.5.2.2.7.1 Symbols

a	equatorial radius, meters
E	oblateness factor = $\left(1 - \frac{\text{minor diameter}}{\text{major diameter}}\right)$
g	acceleration of gravity at equator, meters/sec^2
G	universal gravitational constant
h	altitude above the reference ellipsoid, meters
J	harmonic terms of the potential function
M	mass
P_n	(sinϕ) Legendre polynomial
ϕ	latitude

r	radius from center of earth, meters
u,v,w	axis system ordinates, meters
U	potential function
ϕ	longitude
ω_e	rotational speed of earth $\dfrac{2\pi}{86{,}164.0982 + .00164T}$
T	Julian centuries (36525 days) from 1900 Jan 0.5 U.T.
A_u	astronomical constant

subscripts

e	earth
s	sun
p	planet
m	moon

2.5.2.2.7.2 Gravitational

2.5.2.2.7.2.1 Numerical Values. - In the formula:

$$U = (GM_e/r) \left[1 - \sum_{n=2}^{n} J_n (a_e/r)^n \, P_n \, (\sin \phi) \right]$$

Where P (sin ϕ) is the Legendre polynomial and ϕ is the geocentric latitude, or in alternate notation:

$$(f, \phi) = GM_e/r \left[1 + J/3 \, (a_e/r)^2 \, (1 - 3 \sin^2 \phi) \right.$$

$$+ H/5 \, (a_e/r)^3 \, (3 - 5 \sin^2 \phi) \sin \phi$$

$$\left. + D/35 \, (a_e/r)^4 \, (3 - 30 \sin^2 \phi + 35 \sin^4 \phi) \right]$$

$$GM_e = 3.986032\ (\pm\ 0.000030) \times 10^{14}\ \frac{\text{meters}^3}{\text{sec}^2}$$

$$J_2 = 1082.30\ (\pm\ 0.2) \times 10^{-6}$$

$$J_3 = -2.3\ (\pm\ 0.1) \times 10^{-6}$$

$$J_4 = -1.8\ (\pm\ 0.2) \times 10^{-6}$$

$$J_n = 0.0\ (\pm < 1.0) \times 10^{-6}\quad n \geq 5$$

$$J_{nm} = 0.0\ (\pm < 2.0) \times 10^{-6},\ m = 0$$

$$a_e = 6.378165\ (\pm\ 0.000025) \times 10^{6}\ \text{meters}$$

$$J = 1.62345 \times 10^{-3}$$

$$H = -0.575 \times 10^{-5}$$

$$D = .7875 \times 10^{-5}$$

2.5.2.2.7.2.2 Remarks

2.5.2.2.7.2.2.1 The values of GM_e, H, D and a_e are consistent with the values of geodetic parameters.

$1/E$ = Reciprocal of earth/flattening = 298.30

$g_e = 978.030\ \text{cm/sec}^2$

2.5.2.2.7.2.2.2 The values of a_e, e, g_e are those specified in the DOD World Geodetic System 1960 and are here recommended for the sake of consistency. In addition, they are close to the best estimates for these parameters. Reasonable alternative values based on terrestrial geodetic data; e.g., those in reference 13 differ by less than 20 meters is a_e, .00001 meters^2 in g_e, and 0.1 in $1/f$.

2.5.2.2.7.2.2.3 The value of g_e incorporates a correction of .0013 meters/sec^2 to the Potsdam standard absolute gravity.

2.5.2.2.7.2.2.4 The values of J_3 and J_4 are compromises between the values obtained by the principal investigators of satellite orbits as presented in references 14, 15, and 16, with greatest weight to reference 16 and the given uncertainties are based on the discrepancies between these results. The values of J_2 by these same investigators range from 1082.19 to 1082.79×10^{-6}. The magnitude of effect of the omitted J_{nm} on satellite positions is about ±400 m or less (see reference 17).

2.5.2.2.7.2.2.5 The most serious discrepancy of determination of gravitational parameters is between the GM from terrestrial data, 3.1986032 (±0.000030) x 10^{14} meters^3/sec^2, and that based on the lunar mean motion and the radar measurement of the moon's distance: 3.986141 (0.000040) x 10^{14} meters^3/sec^2. This value depends on the moon/earth mass ratio of 1/81.375 (see reference 8); 3.986048 is obtained from Delano's 1/81.219 (see reference 18). However, the stated uncertainty depends mainly on the uncertainties in the radar measurement and the lunar radius.

2.5.2.2.7.3 Geometrical

2.5.2.2.7.3.1 Numerical Values. - Figure 27 represents the astro-geodetic geoid data station spacing and distribution. The Coordinate System used has its u, v, and w axes earth-centered, earth-fixed, and directed toward the latitudes and longitudes 0°, 0°; 0°, 90° E; and 90° N., respectively.

2.5.2.2.7.3.1.1 Corrections - General. - The corrections to be added to the rectangular coordinated in the u, v, and w system are presented in figure 28. These corrections are based on reference 13.

2.5.2.2.7.3.1.2 Corrections at Stations Not Connected to the Geodetic System. - Stations not connected to any of the principal Geodetic Systems, but which have an astronomic position or which are connected to a local system must be treated in the following way. The geodetic latitude and longitude is to be that of the astronomic or local system, and the u, v, and w coordinated obtained by the equations.

[redacted]

$$u = (\gamma + h) \cos \phi \cos \lambda$$

$$v = (\gamma + h) \cos \phi \sin \lambda$$

$$w = \left[(1 - e^2)\, \gamma + h\right] \sin \phi$$

where

$$\gamma = a_e \, (1 - e^2 \sin \phi)^{-\frac{1}{2}}$$

$$e = 2f - f^2$$

and h is the elevation above the ellipsoid. If a_e = 6378165 meters and f = 1/298.30 are used, and the height above the ellipsoid assumed to be identical with the height above sea level, then the standard error of position in the radial direction should be

$\sigma\,(r) = \pm 45$ meters.

If the geoid heights from figures 7 or 8 of reference 13 are added to the height above sea level, then there will be a slight improvement to about ± 35 meters.

For the horizontal coordinates at a station in a geophysically stable continental area.

$\sigma\,(r\, \phi) = \sigma(r\, \lambda \cos \phi) \approx \pm 170$ meters.

For the horizontal coordinates from a single astronomic position on an island or in a geophysically disturbed area (mountains, etc.)

$\sigma\,(r\, \phi) = \sigma(r \lambda \cos \phi) \approx +350$ meters.

By using the mean position obtained by connecting astronomic observations on opposite sides of an island by traverse this may be improved to about

$\sigma\,(r\, \phi) = \sigma(r\, \lambda \cos \phi) \approx +250$ meters.

By using topographic isostatic corrections of the deflections of the vertical this may further be improved to about

$\sigma\,(r\, \phi) = \sigma\,(r\, \lambda \cos \phi) \approx \pm 200$ meters (for a single station) and $\sigma\,(r) = \sigma\,(r\lambda \cos \phi) \approx \pm 120$ meters (for the mean from observations on opposite sides.)

[redacted]

2.5.2.2.7.3.2 Remarks

The values recommended for Argentina and Australia are based on the assumption of tangency at the geodetic datum "origins" of an $a_e = 6378165+N_o$, 1/298.3 ellipsoid, where N_o is the geoid height at the datum origin given in figures 2 and 3 of reference 13.

The Vanguard Datum was based on the assumption of tangency to NAD at its origin (97°N, 263°E) of the Hough Ellipsoid

$a_e = 6378270$

$f = 1/297.0$

The SAO SP 59 datum (see reference 19) is based on the assumption of tangency to the conventional datums, corrected by gravimetrically computed deflections, of the vertical (except in Argentina), of the International Ellipsoid

$a_e = 6378388$

$f = 1/297.0$

The large differences from reference 13 datum are due mainly to this use of an obsolete ellipsoid and secondarily to the utilization of much less observational data.

Note that all datum shifts are described as translations; there are no rotations. For properly observed geodetic systems, the orientation error is negligible. Orientation of geodetic systems is obtained from the stars through "Laplace stations," at which astronomic azimuth and longitude are observed.

The standard error for difference of position between two stations connected to the same geodetic control system should always be less than ± 20 meters.

The standard errors for astronomic positions in a continental area is based on autocovariance analysis of gravimetry.

The standard error for astronomic positions on islands is based on a sample of 69 islands in the West Indies connected to the continental geodetic system by Hiran trilateration.

2.5.2.2.8 Sun and Planetary Constants. - Certain sun, lunar, and planetary constants to be used are presented in figure 29.

2.5.2.3 Entry, Earth Landing, and Recovery Phase

2.5.2.3.1 Atmospheric Pressure, Density, and Temperature. - The altitude, seasonal, daily and latitude variation of pressure, density, and temperature will be as presented by the revised ICAO reference atmosphere. Because this reference is in the process of publication the 1959 ARDC standard atmosphere will be used until the ICAO data is available.

2.5.2.3.2 Wind Velocity. - The wind velocity which is exceeded only 10 percent of the time is presented in figure 30 for the months of January and July.

2.5.2.3.3 Wave Height. - The wave height which is exceeded only 10 percent of the time is presented in figure 31 for the months of January and July.

3.0 FLIGHT PLAN

3.1 General. - Definitive flight plans for the various missions which will be included in the Apollo program can be formulated only after the design details of the Space Vehicle are better known, mission objectives defined in more detail, and more comprehensive information is available concerning the tradeoffs between the variables which describe each mission phase. There are, however, some preliminary requirements concerning flight plans and some information relative to the choice of trajectories which are presently known. This section is divided into three parts: (1) the preliminary flight plan requirements, (2) lunar landing mission trajectory characteristics and (3) an example flight plan for the lunar landing mission. The preliminary flight plan requirements will serve as a basis for further detail studies. The lunar landing mission trajectory characteristics and example flight plan are for information only.

3.2 Preliminary Flight Plan Requirements. - The following flight plan requirements are considered to be preliminary and a partial list. Further studies and experience in formulating flight plan and Spacecraft design details on the part of NASA, the Principal Contractor, and the Lunar Excursion Module Associate Contractor will enable more definitive requirements to be specified.

a. Launch Site - All earth orbit and lunar missions are to be launched from Cape Canaveral, Florida. This does not preclude the use of other launch sites for systems tests. The launch azimuths are to be within the limitations set by range safety and tracking considerations.

b. Launch Time Window - Lunar mission flight plans must include at least a 2 hour period on launch date in which the mission can be launched either continuously or at discrete intervals.

c. Number of Parking Orbits - Multiple parking orbits are acceptable.

d. Earth Orbits - Earth orbit altitudes for manned orbital flight and parking orbits for lunar missions will be limited to altitudes from 50 to 400 nautical miles.

e. Translunar Insertion Position - Final insertion into the translunar trajectory shall be located such that the trajectory can be determined by the Ground Operational Support System within 15 minutes of translunar insertion burnout.

f. Translunar Midcourse Corrections - The Spacecraft must include provisions for performing translunar midcourse maneuvers.

g. Lunar Orbit - The lunar landing will be initiated from a lunar orbit. The nominal lunar orbit altitude is 100 nautical miles. A 5^{o} plan change capability shall be provided for establishing the initial orbit. The plane change maneuver should be accomplished at the same time as the retro maneuver for establishing the lunar orbit.

h. Lunar Landing - The Lunar Excursion Module will separate from the Command and Service Module and transfer from the circular orbit to an equal period elliptical orbit which does not intersect the moon's surface. The landing, hovering and final touchdown maneuvers will be performed by the Lunar Excursion Module from the elliptical orbit.

i. Lunar Landing Site - Mission plans may call for several lunar landing sites. The following factors will be considered in the choice of a landing site:

(1) Propulsion and fuel requirements.

(2) Maneuvering and hovering capability.

(3) Communication with GOSS.

(4) Illumination.

(5) Temperature of environment.

(6) Surface texture.

(7) Ease of identification.

(8) Length of lunar exploration period.

j. Lunar Launch - There shall not normally be a requirement to reposition the Lunar Excursion Module attitude prior to launch. The lunar launch and ascent phases are accomplished by the Lunar Excursion Module.

k. Rendezvous.- The Lunar Excursion Module will provide the necessary performance to transfer from the elliptical orbit to the circular orbit of the Command and Service Modules and accomplish the rendezvous maneuver with the Command and Service Modules.

l. Transearth Injection.- The Service Module will provide the necessary performance to transfer from the lunar orbit to the transearth trajectory.

m. Transearth Midcourse Corrections.- The Spacecraft must include provisions for performing transearth midcourse maneuvers. The inclination of the transearth trajectory to the earths equator shall be compatible with existing tracking stations.

n. Reentry.- The Command Module shall be capable of reentry over a nominal 30 nautical mile corridor with peak deceleration limited to 10g. The direction of reentry to be with the rotation of the earth.

3.3 Trajectory Characteristics - The trajectory characteristics are presented in the order of the different phases of flight and are for information only.

a. Launch Time Window - In order to provide a launch-time window it is necessary either to maneuver the Launch Vehicle or Spacecraft to intercept a planned nominal trajectory, or to select a new trajectory which will satisfy the mission objectives and which can be obtained at the actual launch time. Both the lunar trajectory selection and maneuvering of the Launch Vehicle methods of obtaining a launch window should be developed for use in the Apollo mission. The discussion of launch window below is limited to lunar trajectory variation.

To a first order of approximation, the Spacecraft can be injected into a lunar trajectory from any parking orbit which passes over the earth surface point which is formed by projecting the line of centers between the earth and the moon at the time of closest initial approach. With no restriction due to the mission objectives or performance loss, a launch could be made at any time of day. The launch window is, therefore, primarily a function of the permissible azimuth swing for launch from Cape Canaveral. Figure 32 shows the launch time window and the maximum inclination of the parking orbit as a function of azimuth variations, positive and negative from due East launches from Cape Canaveral. This launch window is independent of lunar declination and can be obtained for lunar injection toward either the South or North.

b. Parking Orbits - Earth orbit altitude from 50 to 400 N.M. may be required for earth-orbit launch time flexibility. It is expected that the best launch booster performance is obtained with low altitude parking orbits. A nominal value of orbit altitude for direct lunar missions is 600,000 feet. The effect of launch delays on the earth track of the parking orbit and the location of the injection point is shown in figure 33. The extreme orbit paths for a 4 hour launch window are shown as the outside solid lines for the condition where the launch azimuth variation is symmetrical, about a due East launch from Cape Canaveral. The inner broken lines show the extremes for a 2 hour launch window. The launch window results from the use of any trajectory between these extremes. The location of the injection points for certain lunar declinations is shown in figure 33.

c. Injection - The characteristic velocity requirement for injection into translunar trajectories from a 600,000 foot parking orbit is shown in figure 34 for initial engine thrust to space vehicle weight ratios from 0.5 to 1.5. These results are applicable for a specific impulse from 250 to 500. Even though the results shown are terminated at 900,000 feet, it is apparent that with propulsion units with initial thrust to weight ratios less than 1.0, the injection is possible at 200 N.M. altitude without significant losses in performance.

The approximate area covered by the Mercury tracking network for 5° elevation is shown in figure 35 for several altitudes. Comparing figures 33 and 35, it is apparent that many of the Mercury tracking stations are poorly located for coverage at injection of a 4 hour launch window. For maximum Northern declination of the moon, the injection point can be tracked for nearly 4 hours of launch window with the station in Australia. With the moon at maximum Southern declination, the injection point can be covered for about 3 hours of launch window with the tracking stations located in the USA. At lunar declination near 0°, however, the launch time window has restricted coverage. Relocation of some stations and addition of several more would be required to give adequate coverage at all declinations.

d. Translunar Trajectory Characteristics - The nominal translunar trajectory for all lunar missions is one which has a coast return to the earth with acceptable reentry conditions. For circumlunar missions this trajectory must have a flight time and return inclination which returns the vehicle so that the primary landing area is within the reentry maneuver capability of the reentry vehicle. The translunar trajectories for lunar landing missions approach the moon to within 100 nautical miles altitude in order to minimize the landing propulsion requirements.

The inclination of the translunar trajectory plane is a function of the parking orbit inclination and the lunar declination as shown in figure 36.

[redacted]

Varying the inclination of the parking orbit to obtain launch time tolerance as indicated in this section will result in a change in the translunar trajectory inclination which in turn will have some effect on the inclination of the lunar orbit unless plane changes are made during transfer.

The translunar trajectory is tracked with the deep-space network. Figure 37 shows the coverage of the existing deep space network at various altitudes. About 15 minutes after injection, the translunar trajectory will be at high enough altitude for tracking.

e. Lunar Orbit - Flight plans require establishing a circular lunar orbit at 100 nautical miles altitude for lunar landing missions. For lunar orbit missions flight plans may call for both circular and elliptical orbits within the limits of propulsion requirements for the 100 nautical mile circular orbit. Velocity increments for establishing lunar orbits are shown in figure 38.

f. Lunar Landings - A technique for lunar landing is illustrated in figure 39. The Spacecraft arrives behind the moon on a circumlunar trajectory, a transfer is made to a 100 N.M. circular orbit about the moon. The Spacecraft passes over the landing area once and then at the proper position in the orbit the Lunar Excursion Module will be separated from the Spacecraft and a transfer is made from the circular orbit to an equal period elliptical orbit having a pericynthion of 50,000 feet. The landing run is initiated at 50,000 feet altitude. The impulse requirements for landing on the moon for an optimum flight path for elliptical orbits having 100 nautical miles apocynthion and various pericynthions is shown in figure 40 for various initial thrust-to-weight ratios.

g. Lunar Landing Site - Figure 41 shows the lunar landing area available for missions with translunar trajectories which return to earth with posigrade reentry. The available landing area without orbit transfer is limited to a band of latitude approximately $\pm$ 10 degrees about the moon's orbital plane. This band is shown in Figure 41 in respect to the mean libration point. Due to the librations of the moon at some times of the month latitudes as high as 16°

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are obtainable from some translunar trajectories.

h. Lunar Launch - The probable technique for launch of the Lunar Excursion Module from the moon on the return to the Command and Service Modules is to lift off in an essentially vertical maneuver from the local surface and program pitch into an elliptical orbit. The orbit is circularized at apocynthion and rendezvous and docking with the Spacecraft initiated immediately. Injection on the transearth trajectory is made at the proper time. Figure 42 shows the characteristic velocity requirements for vertical launch into elliptical parking orbits.

i. Transearth - The inclination and the time of flight of the transearth trajectory are used to control the reentry in such a way that the reentry track will be over existing network facilities and traverses reasonable recovery areas. Inclination appears to be in the range of from 30° to 35° which makes use of existing facilities and is compatible with landing site in Southern Texas, Hawaii, and Australia. The injection requirements for transfer from lunar orbit to the transearth trajectory are nearly the same as those for establishing lunar orbits shown in figure 34. The nominal reentry for Apollo missions is to be with posigrade motion with respect to the earth to reduce the reentry heating and widen the reentry corridor.

j. Reentry - The 10g reentry corridor for L/D=0.5 is 40 N.M. for an ARDC-1959 standard atmospheres. The effects of atmospheric variation reduce the reentry corridor to about 35 N.M.. Losses due to reentry control techniques which do not use negative lift amount to about 5 N.M.. The maximum reentry corridor for Apollo missions for 10 g maximum deceleration is 30 N.M.

The location of the reentry point is determined by the declination of the moon at the time the transearth trajectory is initiated, the transit time, and the inclination of the return orbit.

The locus of reentry points for a landing site in Southern Texas and in Australia is shown in figure 43 for several lunar declinations. The track of a 30° reentry orbit indicates that a range after reentry of 7,000 to 8,000 miles is required to re-

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turn to Southern Texas for reentry at all lunar declinations. The use of a second landing site in Australia would reduce the maximum required reentry range to about 5,300 nautical miles. Return would be to Texas for Southern declination of the moon and to Australia for Northern declinations of the moon. A typical reentry from a lunar mission for landing in Southern Texas is shown in figure 43 along with the landing areas, possible with an L/D = 0.5 vehicle.

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3.4 Example Flight Plan. - The following flight plan is presented in the order of the different phases of flight and is for information only.

a. Lift-Off Conditions - The launch azimuth is 91°.

b. Lift-Off to Parking Orbit - The characteristics of the flight plan from launch to insertion into a parking orbit at an altitude of 600,000 feet are presented in figures 44a and 44b.

c. Parking Orbit - Ground tracks for the initial earth orbit having a launch azimuth of 91° are presented in figure 45. The parking orbit is circular at an altitude of 600,000 feet. The only portion of the Continental United States over which the Spacecraft passes during the first revolution is Southern Texas.

d. Parking Orbit to Translunar - The location of the beginning of the insertion phase may be anywhere along the parking orbit depending upon the moon's declination. Figure 45 shows earth tracks for an insertion location in the mid-Pacific region. The characteristics of the flight plan from the parking orbit to the translunar trajectory are presented in figure 46.

e. Translunar and Transearth - Figure 47 present the translunar and transearth trajectories for the inertial earth-moon system. The translunar trajectory has the characteristic that if no velocity increment is applied, the Spacecraft will return to earth at acceptable reentry conditions. The pericynthion altitude at the moon is 600,000 feet. The return or transearth trajectory shown in figure 48 represents a continuation of the translunar trajectory with a break of 25 hours for landing on the moon and take-off. The transearth and translunar trajectories combined form a reference circumlunar trajectory with proper correction for the lunar time break.

f. Lunar Orbit - A velocity increment is applied to the Spacecraft in a 100 nautical-mile circular equatorial lunar orbit from the approach pericythion altitude of 100 nautical miles. The landing site is surveyed as the Spacecraft passes over this area during its first revolution. As the Spacecraft approaches a point approximately 180° from the landing site, the Lunar Excursion Module and crew will be separated from the Command Module to await transfer to an elliptical orbit. As the Spacecraft approaches a point 90° from the landing site, the Lunar Excursion Propulsion System provides a velocity impulse to attain the desired elliptical orbit with a pericynthion altitude of 50,000 feet.

g. Lunar Landing - The lunar landing maneuver is initiated at approximately 50,000 feet altitude. The characteristics of the flight plan during the maneuver are presented in figure 49. The maneuver ends at an altitude of approximately 1000 feet at which time the Lunar Excursion Module vertical and horizontal velocity are near zero. The Lunar Excursion Module shall have the capability to hover at this altitude and translate 1000 feet for a time of two minutes.

h. Lunar Launch - The characteristics of the flight plan from lunar take-off to insertion into the elliptical orbit are presented in figure 50. Transfer of the Lunar Excursion Module from its elliptical orbit to Command and Service Module circular orbit will be accomplished by the Lunar Excursion Propulsion System.

i. Rendezvous and Docking - The rendezvous and docking maneuvers will be accomplished by the Lunar Excursion Module with the Command and Service Modules taking corrective action as backup to the Lunar Excursion Module Propulsion System.

j. Launch from Lunar Orbit - The transfer from the 100 nautical mile circular orbit to insertion into the transearth trajectory is accomplished by application of a velocity increment at the insertion. This velocity increment is provided by the Service Propulsion System.

k. Transearth - The transearth trajectory is presented in figure 48.

l. Reentry - The return perigee altitude is 120,000 feet, the velocity at perigee is 36,320 ft/sec, and the reference reentry altitude is 400,000 feet. A ground track of the transearth and reentry phase

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of the flight plan is shown in figure 48. The possible landing area extends from the Western Pacific across the Southern United States and into the South Atlantic. The characteristics of the Spacecraft during reentry are for an L/D ratio of 0.5 and a W/C_DA of 50. The characteristics of the flight plan during reentry are presented in figure 51.

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4.0 SPACECRAFT SYSTEMS. - A description of the characteristics of the Spacecraft and its systems is presented in this section.

4.1 Spacecraft Configuration. - The physical relationship of Spacecraft Modules and major components is specified graphically by schematics with identifying notes. Precise arrangements and detailed mechanical features are not intended to be inferred by the figures.

4.1.1 General Arrangement. - The Spacecraft arrangement for lunar landing missions is shown in figure 52.

4.1.2 Mission Arrangements. - Spacecraft arrangements for the various missions up through lunar landing are shown in figures 53, 54 and 55. These arrangements demonstrate system buildup and off loading techniques convenient to component development and Launch Vehicle capabilities.

4.1.3 Command Module. - The Command Module physical features are defined by aerodynamic and heating performance requirements and crew utility and well being considerations.

4.1.3.1 Geometric Characteristics. - The basic external geometry of the Command Module is shown in figure 56. The Command Module shall be a symmetrical, blunt body developing a hypersonic L/D of approximately 0.50. The L/D vector shall be effectively modulated in hypersonic flight. The modulation is achieved through constant c.g. offset and roll control.

4.1.3.2 Inboard Profile. - Basic arrangements of internal features fundamental to full utilization of the Command Module geometry are shown in figures 57, 58, 59, and 60.

4.1.3.2.1 Load Mitigation Swept Volume. - The crew is suspended on discrete load mitigation devices which normally act on earth-landing impact. The swept volume displayed by this load mitigation stroke is significant and is to be recognized in the internal layout.

4.1.3.2.2 Crew Space Equipment. - Crew space equipment shall be free of protrusions and snags.

4.1.3.2.3 Center-of-Gravity Management. - Consideration shall be given to the arrangement of water stores to permit center of-gravity management. Alteration of crew positions may

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be used for center of gravity management where orientation with respect to displays and controls is not limited.

4.1.3.2.4 Center Aisle. - The center crew support equipment is readily removable and stowable. This provides a center aisle which is required to make full use of the volume and give ready access to all regions.

4.1.3.2.5 Air Lock Operation. - An air lock is extended into the center aisle region and allows exit or egress to or from the Command Module in the environment of space. See figure 57.

4.1.3.2.6 Head Room. - Ground and flight crews performing maintenance, repair and checkout tasks have good head room resulting in an efficient operation. See figure 57.

4.1.3.2.7 Stations. - A variety of crew station combinations are obtained using various arrangements of individual stations. See figure 57.

4.1.3.2.7.1 Left Hand Station. - The left hand station is to be semi-permanently fixed in the near launch condition. Capabilities for movements to better utilize displays and to achieve comfort are to be provided. Access to equipment on the outboard side is achieved by a movement capability which uncovers the area of concern.

4.1.3.2.7.2 Center Station. - The center station is stowable and may be replaced by many combinations of crew orientation during flight.

4.1.3.2.7.3 Right Hand Station. - The right hand station can have the same capabilities as the left hand station or it can be stowed as is the center station depending on mission requirements.

4.1.3.2.8 Visibility. - A broad field of view is provided by windows over the crew's heads in the launch condition. These windows are covered by heat protection elements during launch, reentry and general flare activity at the descretion of the crew.

4.1.3.2.9 Access and Egress Hatches. - Three outward opening hatches are provided in the Command Module just above the crew's heads. The windows for broad field of view are incorporated in these hatches. All hatches are used for ground access, servicing and maintenance. The three hatches provide the crew with individual bailout or other types of emergency egress without interfering with each other's activity. Normal access and egress for crew and all onboard equipment installation is achieved through the use of the large center hatch.

4.1.3.2.10 Earth Landing System.- The Earth Landing System is stowed in the upper portion of the afterbody. See figure 60.

4.1.3.2.11 Reaction Control.- The tankages and other impact sensitive elements for the Reaction Control System are stowed out of the nominal impact area. See figure 60.

4.1.3.2.12 Load Mitigation.- The nominal impact area is provided with load mitigation structure which absorbs the initial energy of impact for the Command Module. See figure 60.

4.1.4 Lunar Excursion Module.- The Lunar Excursion Module general landing configuration is shown in figure 61.

4.1.4.1 Stowed Configuration.- The Lunar Excursion Module is stowed in the adapter region. The general arrangement for the stowed configuration is shown in figure 62.

4.1.4.2 Access.- Free access to the Lunar Excursion Module cabin region shall be provided through panels in the adapter opposite the Lunar Excursion Module access hatch. Free access shall also be provided to the Lunar Excursion Module lower propulsion, equipment and landing gear region through panels in the lower region of the spacecraft adapter.

4.1.4.3 Initial Positioning Configuration.- The Lunar Excursion Module shall be repositioned from its stowed position in the Spacecraft Adapter to a docked position with the Command Module prior to the first midcourse correction. This can be accomplished by either the Service Module Reaction Control System maneuvering the Command and Service Module combination to a docked position or a mechanical system positioning the Lunar Excursion Module to the docked position.

4.1.4.4. Translunar Configuration.- The Spacecraft configuration for the translunar flight and up to separation of the Lunar Excursion Module in lunar orbit for the lunar landing mission is shown in figure 62.

4.1.5 Spacecraft Adapter.- The method of attachment, basic structure and external geometry with the exception of length shall be identical between Spacecraft Adapters for all mission configurations. The adapter structure shall be compatible with the adjoining modules and Launch Vehicle stages. Its overall bending stiffness shall satisfy the requirements of the Launch Vehicle. Its construction shall be buffet and noise resistant in atmospheric phase of flight.

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4.2 Command and Service Modules Systems.- The characteristics of the major systems included in the Command and Service Modules are presented in the following paragraphs:

4.2.1 Guidance and Control System.- The Guidance and Control System is comprised of a Navigation and Guidance System and a Stabilization and Control System. The Stabilization and Control System provides the attitude stabilization and maneuver control requirements for the Command and Service Modules. The Navigation and Guidance System provides steering and thrust control signals for the Stabilization and Control System, Reaction Control Systems, and the Service Propulsion System.

4.2.1.1 Navigation and Guidance System

4.2.1.1.1 System Requirements.- The system requirements of the Navigation and Guidance System are presented below.

4.2.1.1.1.1 Space Vehicle Guidance.- The Navigation and Guidance System shall be capable of controlling the injection of the Spacecraft and of providing a monitoring capability of injection guidance to the crew. This shall be accomplished for both direct ascent and for injection from a parking orbit.

4.2.1.1.1.2 Midcourse Guidance.- The Navigation and Guidance System shall provide navigation data and compute velocity corrections in cislunar space. Enroute to the moon a mission abort capability shall be provided.

4.2.1.1.1.3 Reentry Guidance.- The Navigation and Guidance System shall be capable of guiding the Command Module during reentry through the earth's atmosphere to a preselected landing site on the earth. This capability shall be provided for reentry from lunar missions and earth orbits, from preinjection aborts, and from postinjection aborts.

4.2.1.1.1.4 Lunar Orbit.- The Navigation and Guidance System shall provide a capability for establishing lunar orbits.

4.2.1.1.1.5 Rendezvous.- The Navigation and Guidance System shall be capable of accomplishing a rendezvous between the Command Module and the Lunar Excursion Module.

4.2.1.1.2 System Description.- The Navigation and Guidance System shall consist of the following basic components:

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Inertial Measurement Unit

Optical Measurement Unit

Computer

Control and Display Unit

Displays and Controls

Electronics

Chart Book

Star Catalog

Cabling

The system shall achieve simplicity and reliability by effectively employing the crew whenever equipment design advantage and crew capability are compatible. The system shall achieve operational versatility but, when versatility results in disproportionate increase in equipment complexity, onboard versatility shall be sacrificed and reliance shall be placed upon ground assistance. The system shall be reliable but reliability shall be obtained by the use of system or subsystem redundancy only if it cannot be obtained by ground cooperation and/or onboard emergency systems.

4.2.1.2 Stabilization and Control System

4.2.1.2.1 System Requirements.- The system requirements for the Stabilization and Control System are as follows:

4.2.1.2.1.1 Atmospheric Abort.- Flight path control during the thrusting period of atmospheric abort and stability augmentation after Launch Escape Propulsion System separation.

4.2.1.2.1.2 Extra Atmospheric Abort.- Orientation, attitude control, and reentry stabilization and control. The system shall accept commands from the guidance system for thrust vector control and reentry control.

4.2.1.2.1.3 Parking Orbit.- Stabilization of the Spacecraft while in a parking orbit.

4.2.1.2.1.4 Translunar and Transearth.- Stabilization and control during midcourse flight both outbound and inbound. The control technique shall provide fuel economy and shall satisfy all navigation requirements as well as solar orientation and antenna-pointing requirements. Attitude control and orientation for application of midcourse corrections shall be provided.

4.2.1.2.1.5 Lunar Orbit.- Stabilization and control during lunar orbit.

4.2.1.2.1.6 Orbital Rendezvous and Docking.- Stabilization and control of the Command and Service Module during rendezvous and docking with the Lunar Excursion Module.

4.2.1.2.1.7 Reentry.- Control requirements for reentry guidance. Reaction jets will be employed for three-axis stabilization. Reentry control will be provided by rolling the vehicle which is trimmed at an L/D.

4.2.1.2.1.8 Earth Landing.- Stabilizing and controlling the Command Module with respect to the flight direction in the earth landing configuration. Command control will be by the crew employing visual reference.

4.2.1.2.1.9 Special Control Features.- Consideration shall be given to methods for optimizing overall system design for midcourse flight by integrating requirements for Spacecraft three axis control and antenna-pointing requirements.

4.2.1.2.2 System Description.- The Stabilization and Control System shall consist of the following basic components:

Attitude reference
Rate sensors
Control electronics assembly
Manual controls
Displays
Power supplies

4.2.1.2.2.1 Attitude Reference.- The attitude reference system provides angular displacement signals to the Stabilization and Control System and instrument panel displays. The primary reference system is provided within the Navigation and Guidance System.

Requirements for additional sensors follow.

4.2.1.2.2.1.1 Standby Inertial Reference.- A standby reference which is capable of retaining an inertial reference throughout any combination of Spacecraft maneuver. This system may be erected by the primary reference system but it must be capable of having erected to an inertial reference independent of the primary navigation system. It should also be capable of driving panel displays.

4.2.1.2.2.1.2 Special Sensors.- Non-gyroscopic sensors are required for solar orientation during midcourse flight and for third-axis control in connection with antenna-pointing requirements. Consideration should be given to the use of the outputs of these sensors to control directly through the switching logic of the electronic assembly and to the use of derived rate from the sensor output.

4.2.1.2.2.2 Rate Sensors.- Three axes rate gyro packages shall provide stability augmentation during propulsion modes, maneuvers and reentry. They also serve as a necessary sensor for the rate command system and require a dynamic range capable of dealing with all vehicle configurations and mission requirements. Redundancy shall be provided compatible with the overall system configuration.

4.2.1.2.2.3 Control Electronics Assembly.- The Stabilization and Control System control electronics assembly shall accept command inputs from the Navigation and Guidance System during periods of thrust vector control, periods of tracking for navigation purposes, and from the Stabilization and Control System attitude reference at all other times. The control electronics assembly shall supply thrust command signals to the attitude control propulsion motors to establish correct orientation, stable limit cycle operation, and damping throughout all phases of the mission. The control electronics shall use pulse modulation of similar techniques by which the desired objectives of economical limit cycling, accurate control during periods of large disturbances, and satisfactory maneuver rates can all be achieved with the same switching logic. Flexibility to deal with all vehicle configurations and mission requirements shall be attained by the provision of adjustments for parameters such as attitude dead band, rate limits, and attitude to rate gain. To ease the control task of the pilot, the system must be capable of accepting discrete "dialed" orientation commands or provide an attitude followup for reengagement of attitude hold when the maneuver is completed. The control electronics shall be of modular contruction and provide the necessary redundancy and inflight maintenance capability.

4.2.1.2.2.4 Manual Control.- The suggested method of maneuvering by the pilot is by opening the outer loop and imposing rate commands on the inner rate stabilization loop. The manual controls shall be capable of operating all reaction control motors by direct electrical connection, providing emergency operation in case of rate gyro or other automatic system failure. Design of the controls shall provide acceptable feel characteristics for all conditions of flight environment. Provision for the translational control by the crew for docking and hovering phases of the mission shall be compatible with the attitude control system concept.

4.2.1.2.2.5 Displays.- Displays shall be commensurate with crew requirements.

4.2.1.2.2.6 Power Supplies.- The Stabilization and Control System shall generate all levels of DC and AC voltage requirements internally from the basic vehicle electrical supply. Choice of operating frequencies and provision of redundancy in the power supplies shall be governed by the requirements for compatibility between Navigation and Guidance and Stabilization and Control Systems.

4.2.2 Service Propulsion System

4.2.2.1 General Description.- The Service Propulsion System will be located in the Service Module and be capable of meeting the requirements for:

a. Abort propulsion after jettison of Launch Escape Propulsion System.

b. All major velocity increments and midcourse velocity corrections for missions prior to lunar landing mission.

c. All major velocity increments required for trans-lunar midcourse velocity corrections, placing the Spacecraft into a lunar orbit, for rendezvous of the Command and Service Module with the Lunar Excursion Module on a back-up mode, for transfer of the Command and Service Module from lunar orbit to insertion into the transearth trajectory, and transearth midcourse velocity correction for lunar missions.

A suggested single engine schematic configuration is shown in figure 63. The Service Propulsion System will utilize earth-storable, hypergolic propellants, will include a single engine and will have a pressurized propellant feed system.

4.2.2.2 System Requirements.- The Service Propulsion System will be required to function in several normal and emergency modes, depending upon the mission for which it is being used.

4.2.2.2.1 Earth Orbit Mission

4.2.2.2.1.1 Earth Orbital Retrograde Velocity.- A retrograde velocity is required to reenter the Spacecraft from earth orbital mode.

4.2.2.2.1.2 Earth Orbital Corrections.- A velocity increment is required to correct earth orbit after insertion by Launch Vehicle.

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4.2.2.2.1.3 Post Atmospheric Abort.-Mission abort during post atmospheric portion of launch trajectory will be accomplished by the Service Propulsion System. As the Launch Escape Propulsion System is to be jettisoned shortly after escape from the atmosphere, the Service Propulsion System will be utilized for velocity increment as required to provide separation from the Launch Vehicle, reentry control, and landing point selection if required.

4.2.2.2.2 Circumlunar Mission

4.2.2.2.2.1 Midcourse Velocity Corrections.-The mission trajectory selected will influence the magnitude of midcourse velocity corrections required for this mission. The Service Propulsion System will supply gross velocity increments not supplied by the Reaction Control System.

4.2.2.2.2.2 Launch Abort at Sub-Orbital Velocities.-Mission abort during post atmospheric portion of launch trajectory will be accomplished by the Service Propulsion System. After the Launch Escape Propulsion System is jettisoned, the Service Propulsion System will be utilized for velocity increment as required to provide separation from the Launch Vehicle, reentry control, and landing point selection if required.

4.2.2.2.2.3 Launch Abort at Super-Orbital Velocities.-A velocity increment is required to separate the Spacecraft from the Launch Vehicle and to reorient the total velocity vector such as to allow early reentry or safe orbital stabilization.

4.2.2.2.3 Lunar Orbit Missions

4.2.2.2.3.1. Midcourse Velocity Corrections.-The mission trajectory selected will influence the magnitude of midcourse velocity corrections required for this mission. The Service Propulsion System will supply gross velocity increments not supplied by the Reaction Control System.

4.2.2.2.3.2 Lunar Capture.-In the vicinity of the moon the Service Propulsion System will supply velocity increment as required for insertion into lunar orbit from a free return, circumlunar trajectory 5° out of the plane of the lunar orbit.

4.2.2.2.3.3 Lunar Orbit Transfer.-The velocity increment is as required to transfer from a circular to elliptical lunar orbit.

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4.2.2.2.3.4 Lunar Orbit Velocity.- The velocity increment is as required for lunar orbit escape and earth return.

4.2.2.2.3.5 Post-Atmospheric Abort.-Mission abort during post-atmospheric portion of launch trajectory will be accomplished by the Service Propulsion System. After the Launch Escape Propulsion System is jettisoned the Service Propulsion System will be utilized for velocity increment as required to provide separation from the Launch Vehicle, reentry control, and landing point selection if required.

4.2.2.2.3.6 Super-Orbital Abort.-The velocity increment is as required to separate the Spacecraft from the Launch Vehicle and to reorient the total velocity vector such as to allow early reentry or safe orbital stabilization.

4.2.2.2.3.7 Post-Injection Abort.-The velocity increment is as required to separate the Spacecraft from the Launch Vehicle and to reorient the total velocity vector such as to allow early reentry or safe orbital stabilization.

4.2.2.2.4 Lunar Landing Mission

4.2.2.2.4.1. Midcourse Velocity Correction.-The mission trajectory selected will influence the magnitude of midcourse velocity corrections required for this mission. The Service Propulsion System will supply gross velocity increments not supplied by the Reaction Control System.

4.2.2.2.4.2. Lunar Capture.-In the vicinity of the moon the Service Propulsion System will supply velocity increments as required for insertion into lunar orbit from a free-return circumlunar trajectory 5° out of the plane of the lunar orbit.

4.2.2.2.4.3. Lunar Orbit Escape Velocity.-The velocity increment is as required for lunar orbit escape and earth return.

4.2.2.2.4.4 Post Atmospheric Abort.-Mission abort during post-atmospheric portion of launch trajectory will be accomplished by the Service Propulsion System. After the Launch Escape Propulsion System is jettisoned, the Service Propulsion System will be utilized for velocity increment as required to provide separation from the launch vehicle, reentry control, and landing point selection as required.

4.2.2.2.4.5 Super Orbital Abort.-The velocity increment is as required to separate the Spacecraft from the Launch Vehicle and to reorient the total velocity vector such as to allow early reentry or safe orbital stabilization.

4.2.2.2.4.6 Post Injection Abort.-The velocity increment is as required to separate the Command and Service Modules from the launch vehicle and to reorient the total velocity vector such as to allow early reentry or safe orbital stabilization.

4.2.2.3 System Operation

4.2.2.3.1 Operating Features.-Helium tanks shall be positively sealed by redundant valves prior to use to prevent leakage. Primary and secondary propellant pressurization regulators are required. Propellant utilization control is required to maintain proper oxidizer/fuel ratio. This may be accomplished through regulating either oxidizer or fuel flow rates. It is desirable to minimize the number of valves required to open to obtain ignition. Propellant utilization control should provide for primary and secondary mode of operation. If multiple oxidizer and fuel tanks are used, cross ties to allow use of primary or secondary controls with any tank of the regulated fluid (oxidizer or fuel) shall be provided. Isolation valves shall be provided in these tie lines. If multiple fuel and oxidizer tanks are used, each tank should be emptied prior to use of next tank. Automatic switch over from tank to tank with manual override is required. Propellant for large velocity requirements such as lunar escape shall be fed from the main propellant tanks. Propellant for small velocity requirements such as mid-course corrections will be fed from positive explusion-tanks common with the Reaction Control System or auxiliary positive explusion tanks.

4.2.2.3.2 Safety Features.-Filters to protect regulators, control valves, and propellant injectors are required. Check valves to prevent oxidizer-fuel cross flow shall be provided in pressurization lines. There shall be relief valves to relieve high propellant tank pressures. Burst discs shall protect relief valves from propellant contamination. Redundant propellant valves are required. Manual override provisions on automatic solenoid valves and control valves shall be required. Helium and propellant tanks are to be sealed prior to use. Maximum use of welded or brazed lines and fittings to minimize leak points is desirable. Modular concept of replacement of subsystems is desirable.

4.2.2.3.3 Preflight Checkout.-Fittings are to be provided to gas leak check and purge all parts of the system and to flow check all regulators and control valves and to check normal and emergency valve sequence. Provisions for checking gimballing system prior to operation shall be required. Provisions for checks of all sensors and instrumentation required. Means for cleaning or replacement of system filters prior to flight shall be provided. System shall be static fired as an entire system prior to flight including Command Module and other Service Module systems.

4.2.2.4 Crew Participation (Displays and Control)

4.2.2.4.1 Monitoring Function. - During flight and non-operating periods the crew shall monitor tank pressures, leakage rates, and temperatures. Instrumentation of these items is therefore required. During engine operation, crew shall be able to monitor such system operating parameters as propellant and helium pressures, chamber pressure, and temperatures. Prior to and during engine operation, the crew shall be able to monitor engine gimbal operation. The crew shall be able to monitor all engine valving position. Remaining quantities of oxidizer and fuel shall be presented to the crew during operation. Some means of indicating reserve propellant remaining and propellant utilization system operation are desired.

4.2.2.4.2 Normal Operation. - Preparation of system for engine ignition shall be a crew function. Actual firing shall be an automatic function performed by the guidance system. The crew shall be able to monitor the automatic function. The crew shall be able to monitor automatic switchover function from one oxidizer or fuel tank to another provided multiple tanks are used.

4.2.2.4.3 Emergency Operation. - There shall be a means provided to automatically and/or manually initiate system operation for abort capability in event of booster failure. Automatic engine shutdown of redundant engines in event of low chamber pressure, high external temperatures indicating external fire or other engine failures shall be provided. Automatic switchover to redundant regulator in event of helium primary regulator failure in the open mode is required to prevent helium loss. If multiple oxidizer and fuel tanks are used, manual override of automatic tank switching device shall be provided. The crew shall be able to manually shutdown the engine or engines and shall be able to manually override any automatic function. Provisions for in-flight, extra vehicular access by the crew for inspection, and maintenance shall be provided.

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4.2.2.5 Guidance System Requirements

4.2.2.5.1 Thrust Vector Control. - This system shall be designed to control the thrust vector during midcourse velocity corrections with frequent restart capability. The gimbal actuators shall be redundant for this engine. These actuators shall have the necessary response characteristics to maintain proper trajectories.

4.2.2.5.2 Velocity Cut-off Control. - This system shall be designed to control the velocity cut-off during midcourse velocity corrections. The valve closing times should be held within limits to prevent damage from hydraulic hammer effect. Engine surge characteristics shall be investigated for different valve designs. Engine cut-off impulse accuracy shall be known within 2% of that required for the minimum operating cycle. The magnitude of impulse error shall not exceed 150 lb-sec.

4.2.2.6 Propellants. - The Service Propulsion System shall use an earth storable hypergolic bipropellant combination.

4.2.2.6.1 Oxidizer. - The oxidizer shall be nitrogen tetroxide (N_2O_4) with nitrous oxide (N_2O) added to depress the freezing point if necessary.

4.2.2.6.2 Fuel. - The fuel shall be either monomethylhydrazine (MMH) or a mixture of 50% hydrazine (N_2H_4) and 50% unsymmetrical dimethylhydrazine (UDMH).

4.2.2.7 Component Selection. - The example schematic shows a single engine. The schematic indicates the essential components and their functional interelationship.

4.2.2.7.1 Tanks. - Toroidal tanks shall not be used with multiple thrust chambers.

4.2.2.7.2 Pressurization. - Ambiently stored helium gas shall be used for pressurization. Tanks shall be held to minimum consonant with packaging requirements.

4.2.2.7.3 Control Systems. -

4.2.2.7.3.1 Thrust Vector Control. - Thrust vector control shall be attained by redundant gimballing. Electromechanical and electrohydraulic systems should be compared.

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4.2.2.7.3.2 Liquid Level Sensing System. - A liquid level sensing system is required to indicate propellant level in the tanks during periods of acceleration so that the crew can check propellants available.

4.2.2.7.3.3 Propellant Utilization System. - A propellant utilization system shall be supplied to ensure efficient utilization of propellant.

4.2.2.7.4 Performance. - The minimum delivered vacuum specific impulse shall be 315 $\frac{\text{lb-sec.}}{\text{lb.}}$

4.2.3 Reaction Control System. - The Command and Service Modules shall include Reaction Control Systems to provide the impulse for attitude control and stabilization. The Service Module System shall also be capable of minor translational velocity increments.

4.2.3.1 Command Module Reaction Control System. - This system will be used only after separation of the Command Module from the Service Module.

4.2.3.1.1 System Requirements. - The system shall provide three axis control prior to the development of aerodynamic moments, roll control during reentry and landing, and pitch and yaw rate damping during reentry and deployment of the landing system. A roll acceleration of at least 10^{o}/sec/sec shall be provided during reentry. The pitch and yaw acceleration shall be compatible with their requirements.

4.2.3.1.2 System Description

4.2.3.1.2.1 General. - The suggested Reaction Control System is pulse modulated, pressure fed, and utilizes earth storable hypergolic fuel. Fuel tanks shall be positive expulsion type. The Command Module has two independent systems as shown in figure 64 and located as shown in figure 65. Each is capable of meeting the total torque and propellant storage requirements. Each system consists of helium pressurization, propellant storage, distribution and thrust chamber subsystems.

4.2.3.1.2.2 Propellants. - The Reaction Control System shall use an earth storable hypergolic bipropellant combination.

4.2.3.1.2.2.1 Oxidizer. - The oxidizer shall be nitrogen tetroxide (N_2O_4) with nitrous oxide (N_2O) added to depress the freezing point if necessary.

4.2.3.1.2.2.2 Fuel. - The fuel shall be either monomethylhydrazine (MMH) or a mixture of 50% hydrazine (N_2H_4) and 50% unsymmetrical dimethylhydrazine (UDMH).

4.2.3.1.2.3 Distribution. - Each system shall consist of six thrust chamber subystems installed to provide six degrees of control as shown in figure 64. Either system shall be capable of remote isolation by the crew by means of reversible valves.

4.2.3.1.2.4 Thrust Chambers.- Since the chambers and nozzles must be buried within the module, they should be ablatively cooled. Alternate methods may be considered which would also maintain compatible external temperatures on the units. Heat protection of control valves shall be provided if necessary.

4.2.3.1.3 System Operation

4.2.3.1.3.1 Servicing and Checkout.- Each system shall be designed to allow preflight servicing, checkout, and deactivation.

4.2.3.1.3.2 Flight.- The systems shall be designed to operate simultaneously from the crew manual controls by means of electrical outputs. Malfunction detection means should be investigated which would allow for shutdown of one system if a thruster in that system fails.

4.2.3.2 Service Module Reaction Control System.- This system will provide the impulse for attitude control and stabilization for the Spacecraft in all phases of flight except during periods that other propulsion systems are active. In addition, the system shall provide attitude control and stabilization for the Launch Vehicle-Spacecraft combination in earth parking orbit. The system shall also provide minor translational capability for minor midcourse corrections, terminal rendezvous and docking as well as ullage accelerations for Service Propulsion System, if necessary. The system shall contain the flexibility required to allow its use in all missions.

4.2.3.2.1 System Requirements.- The final requirements for the system will be coordinated with the Contractor as they become available. A preliminary estimate indicates that 400 pounds of propellant including 30 percent reserve will be adequate for all missions, provided a minimum pulse not to exceed 20 milliseconds with a 90 percent pulse efficiency is attained.

4.2.3.2.2 System Description

4.2.3.2.2.1 General.- The Reaction Control System is pulse modulated, pressure fed, and utilizes earth storable hypergolic fuel. Fuel tanks shall be positive expulsion type. The suggested Service Module Reaction Control System has two independent systems as shown in figure 66 and located

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as shown in figure 67. Each is capable of meeting the total torque and propellant storage requirements. The system shall consist of 8 roll, 4 pitch and 4 yaw, thrust chamber subsystems. It shall be designed to allow translation in six directions. The system has two sets of propellant tanks and pressurization subsystems. The thrust shall be installed so that normal translational thrust vectors are in the vicinity of the vehicle center of gravity for the earth-orbiting mission. The roll thrusters will be used for pitch and yaw maneuvering whenever the Lunar Excursion Module is attached. Each set of tanks supplies six small thrust chambers capable of control in all 6 directions during navigational sightings.

4.2.3.2.2.2 Propellant.- The propellants shall be the same as those used for the Service Propulsion System.

4.2.3.2.2.3 Distribution.- Each set of tanks normally supply one thruster of each couple and the feed systems from the two sets of tanks are normally isolated. Figure 66 shows a system utilizing positive expulsion tanks. The method of storage must satisfy Reaction Control and minor mission velocity requirements. Each set of thruster chambers is capable of being isolated by the crew.

4.2.3.2.2.4 Thrust Chambers.- An intensive program should be undertaken to develop and evaluate both the radiation-cooled and ablation-cooled thrust chambers for this application. Particular attention should be given to the effects of intermittent firing of the chambers in a hard vacuum.

4.2.3.2.3 System Operation

4.2.3.2.3.1 Servicing and Checkout.- Each system shall be designed to allow preflight servicing, checkout, and de-activation.

4.2.3.2.3.2 Flight.- The system shall be designed to operate from manual-electric and automatic-electric input signals. A major effort is required in order to develop satisfactory means for malfunction detection in the system especially in the area of small leakage rates.

4.2.4 Launch Escape System.- The Command Module shall be fitted with a Launch Escape System as shown in figure

4.2.4.1 System Requirements. - The Launch Escape System separates the Command Module from the Launch Vehicle in the event of failure or imminent failure of the Launch Vehicle during all atmospheric phases. The performance of the Launch Escape System is dictated by the requirements of crew response and/or of the Abort Sensing Implementation System of the Launch Vehicle and the structural capability of the Command Module to resist overpressures due to Launch Vehicle explosion. Two critical flight modes are recognized.

4.2.4.1.1 Pad Escape.- For escape prior to or shortly after lift-off, the Launch Escape System separates the Command Module from the Launch Vehicle and propels the Command Module to an altitude of at least 5000 feet and a lateral range at touchdown of at least 3000 feet without exceeding the crew tolerances. Stabilization and lateral control, if required, shall be provided.

4.2.4.1.2 Maximum Dynamic Pressure Escape.- For escape at maximum dynamic pressure, the Launch Escape System separates the Command Module from the Launch Vehicle during thrusting of the Launch Vehicle and propels the Command Module a safe distance from the Launch Vehicle. The Launch Escape System and the Command Module combination are aerodynamically stable or neutrally stable and have sufficient lateral control to obtain the maximum possible Launch Vehicle "miss" distance consonant with the crew tolerances.

4.2.4.2 Propulsion.- The basic propulsion system is a solid-fuel rocket motor with "step" or regressive burning characteristics. Its nozzles are canted to avoid direct impingement of the exhaust jets on the Command Module.

4.2.4.3 Stabilization and Control.- Stabilization and lateral control shall be provided.

4.2.4.4 Escape System Jettison.- The Launch Escape System is jettisoned at approximately maximum altitude after "pad escape," or an appropriate time after high dynamic pressure escape, and is separated from the Command Module by a solid-fuel rocket motor. For normal flights, separation is effected by the main propulsion motor during early operation of the second stage of the Launch Vehicle.

4.2.4.5 Initiation and Control Mode Selection.- Initiation of escape and subsequent selection of control modes is the responsibility of the crew. There shall be no responsibility assigned to ground control or automatic systems unless there is insufficient time and/or information for crew action.

4.2.5 Earth Landing System. - The Command Module includes an Earth Landing System to be used under all flight conditions for earth landing requirements.

4.2.5.1 System Requirements. - The system satisfies the following requirements after normal reentry, maximum dynamic pressure escape, and pad escape.

4.2.5.1.1 Postentry Stabilization. - Stabilizes the Command Module during postentry descent.

4.2.5.1.2 Velocity Control. - Reduces the vertical touchdown velocity to not more than 30 feet per second at an altitude of 5000 feet.

4.2.5.1.3 Impact Attenuation. - Reduces impact acceleration such that neither the Command Module primary structure or flotation is impaired. Any further attenuation required by the crew shall be provided by individual, crewman shock attenuation devices.

4.2.5.1.3.1 Impact Attitude. - For nominal land landings, the capsule should impact at an angle of -15° with the c.g. forward. See figure 60. This locates the crew in a feet first position. For water landings an impact of 15° with the c.g. aft and the crew located in head first position is desirable. The maximum emergency limit "g" forces must not be exceeded for any landing regardless of capsule orientation.

4.2.5.1.4 Postlanding. - The system provides any necessary flotation, survival, and location aids.

4.2.5.2 System Description. - The landing system consists of 3 FIST type drogue chutes deployed by mortar and a cluster of three simultaneously deployed landing parachutes. Landing parachutes are sized such that satisfactory operation of any two of the three will satisfy the vertical velocity requirement. The Command Module is hung in a canted position from the parachute risers and oriented through a roll control to favor impact attenuation.

4.2.5.3 Initiation and Control. - Initiation of all functions can be manually controlled. Command Module roll orientation prior to impact can be also manually controlled.

4.2.6 Structural System.- In addition to the fundamental load carrying structures, the Command and Service Modules Structural System shall include meteoroid protection, radiation protection inherent in the structure, and **passive heat protection systems.** Primary structures shall be designed and evaluated in accordance with standard aircraft practice with the exception that no structure shall require pressure stabilization.

4.2.6.1 Command Module

4.2.6.1.1 Reentry Thermal Protection.- The Command Module's external thermal protection shall utilize the planned degradation of suitably reinforced plastics. The forebody shall utilize a charring ablator capable of sustaining high surface temperatures and providing effective blockage of external heat fluxes. Adequate reinforcement of the shield shall be provided to ensure shield integrity and satisfactory performance through all phases of flight.

Afterbody heat protection shall also utilize planned material degradation but consideration should be given to providing protection which is better suited to the more moderate heat flux environment and thinner gauges of the afterbody.

Passive control of heat fluxes to the interior of the Command Module shall be utilized. Circulatory heat exchange system used only for internal cabin comfort control.

Egress hatches, windows, umbilicals, etc., shall be located on low heat flux regions of the Command Module when possible and shall be covered by doors fairing smoothly to the capsule contour.

The reinforced plastic shall be mounted on a relatively rigid brazed or welded sandwich construction support capable of withstanding temperatures considerably in excess of conventional bonding temperatures. The adhesive bond between the ablator and the sandwich support must be capable of withstanding the low temperatures during the space flight and shall not be subjected to temperatures during reentry beyond demonstrated state-of-the-art capabilities.

4.2.6.1.2 Pressure Vessel.- The pressure cabin will be separate from the thermal protection system and will consist of an aluminum shell with longerons to react the concentrated loads from the escape tower and parachute attachments, and act as edge members for windows and hatches. Consideration will be given to the venting of the space between the pressure cabin and thermal protection. Viewing ports will form an integral part of the exit hatch.

4.2.6.2 Service Module.- The Service Module shall consist of a sandwich shell compatible with the noise and buffet requirements and the meteorite penetration requirements. In addition, it should maintain structural continuity with adjoining modules and be compatible with the overall bending stiffness requirements of the Launch Vehicle.

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4.2.7 Crew Systems

4.2.7.1 Flight Crew

4.2.7.1.1 Size and Number.- The flight crew shall consist of three men. The size of each crew member shall be between the 10th and 90th percentile as defined in reference 20.

4.2.7.1.2 Division of Duties.- Tasks shall be so apportioned as to make maximum utilization of all three crew members. During launch, entry, and similar critical mission phases, division of key tasks amongst the three crew members shall be as nearly equal as possible. Division of specific responsibilities shall be as follows:

4.2.7.1.2.1 Commander (Pilot).- He shall control the vehicle in manual or automatic mode, during all phases of the mission. He shall select, implement and monitor the modes of navigation and guidance. He shall monitor and control key areas of all systems during time critical periods. He shall occupy either the left or center couch during launch and reentry.

4.2.7.1.2.2 Co-Pilot.- The co-pilot shall be second in command of the vehicle. He shall support the commander as alternate pilot and navigator. During critical mission phases, he shall monitor certain critical parameters of the spacecraft and propulsion systems. He shall occupy either the left or center couch during launch and reentry.

4.2.7.1.2.3 Systems Engineer.- During critical mission phases he shall monitor certain critical parameters of the spacecraft and propulsion systems. When certain systems are placed on board primarily to be evaluated for later Apollo vehicles, he shall be responsible for their operation, monitoring and evaluation. He shall occupy the right hand couch during launch and reentry.

4.2.7.1.2.4 General Duties.- All crew members shall be cross trained so as to be able to assume the tasks usually performed by fellow crew members. Each shall stand watches during non-critical mission phases and perform all command and systems monitoring functions during such watches. While the commander shall be the principal navigator, the taking of navigational fixes and performance of associated calculations may be divided equally amongst all crew members.

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4.2.7.2 Crew Integration

4.2.7.2.1 Displays and Controls

4.2.7.2.1.1 Arrangement.- Arrangement of displays and controls shall reflect the division of crew tasks. Critical piloting displays and controls shall be duplicated at the adjacent command and co-pilot stations. Non-duplicated piloting displays and controls shall be readily visible and accessible to both commander and co-pilot. All controls shall be of the self locking type, or guarded to prevent inadvertent actuation. Instrument mountings shall ensure legibility of necessary displays during periods of vibration.

4.2.7.2.1.2 Manual Controls.- Manual control inputs to the Command Module attitude control system shall be provided at the left hand and center seats.

4.2.7.2.1.3 External View Devices.- Windows and other external viewing devices shall be provided to permit maximum feasible use of direct vision during rendezvous, earth landing, scientific observations and monitoring of crewmen operating outside the Spacecraft.

4.2.7.2.1.4 Operation by Single Crew Member.- Controls and displays shall be so arranged as to permit one crew member to return the vehicle safely to earth. However, this requirement shall not cause systems designs which result in degraded reliability for three man operation.

4.2.7.2.2 Crewspace Arrangement

4.2.7.2.2.1 Primary Duty Stations.- The primary displays, controls, and support systems shall be so arranged that the crew members are generally side by side during launch, entry, and similar critical mission phases. During other mission phases at least one couch shall be completely removed or stowed in order to provide additional work space and access to other work areas within the Command Module.

4.2.7.2.2.2 Secondary Duty Stations.- Areas for taking navigation fixes, performing maintenance, food preparation, and certain scientific observations may be separate from the primary duty stations.

4.2.7.2.2.3 Watch Station.- One of the primary duty stations shall be the station at which one crew member stands watch during non-critical mission phases. Some immediate control over all critical systems must be accessible at that station.

4.2.7.2.2.4 Sleeping.- There shall be a specific area assigned for sleeping. It shall accomodate a single crewman. It shall be placed in such a manner as to permit control of noise, light, and other distractions.

4.2.7.2.2.5 Toilet.- There shall be a specific area assigned to a toilet for collection of human waste. It shall accomodate a single crewman. It shall be so placed as to permit temporary partitioning for privacy.

4.2.7.2.2.6 Radiation Shielding.- The mass of the Spacecraft modules shall provide the majority of the bulk shielding. Arrangement of this mass shall be optimized to provide maximum shielding protection, both by its arrangement and by the position of the crew members without unduly compromising the system.

4.2.7.3 Crew Equipment

4.2.7.3.1 Acceleration Protection

4.2.7.3.1.1 Design Approach.- Design of the crew support and restraint systems shall be integrated with the design of the Earth Landing and Launch Escape Systems.

4.2.7.3.1.2 Couch.- Each crewman shall be provided with a support couch for protection against acceleration loads. The couch shall provide full body and head support during all nominal and emergency acceleration conditions. During launch and entry, the couch shall support the crew members at body angles specified in figure 68. The couch shall be adjustable to permit changes in body and leg angles to improve comfort during non-acceleration mission phases. Couches shall be so constructed as to permit crewmen to interchange positions. To meet the interchange requirements, sizing may be accomplished by use of simple couch adjustment devices. Couch construction and materials shall not amplify any accelerating forces by a factor of more than 1.2. The couch shall accomodate a crewman wearing a back type or seat type personal parachute. The parachute shall remain in the couch when the crewman leaves his restraint system. The couch shall accomodate crewmen in both pressurized and unpressurized space suits when used. The couch shall permit ease in ingress and egress during all nominal and emergency mission conditions. All couches shall be easily removable for the purpose of preflight and inflight maintenance.

.2.7.3.1.3 Restraint System.- A restraint system shall be provided with each couch. The system shall allow the interchange of crewman with simple attachment and adjustment for comfort and sizing. The torso portion of the restraint system shall also serve as a personal parachute harness. The restraint system shall provide adequate restraint for all nominal and emergency flight phases; landing loads and high dynamic pressure aborts are particularly significant in design of the restraint system.

4.2.7.3.1.4 Impact Attentuation.- Impact attenuation beyond that required to maintain general Command Module integrity shall be obtained through use of discrete shock mitigation devices for individual crew support and restraint systems. Attenuation devices shall provide for lateral as well as transverse acceleration loads.

4.2.7.3.1.5 Vibration Attenuation.- Vibration attenuation beyond that required to maintain general Spacecraft integrity shall be provided with each support and restraint system. Such vibration attenuation systems must keep vibration loads transmitted to the crew within tolerance limits and also permit the crew to exercise necessary control and monitoring functions.

4.2.7.3.1.6 Restraint for Weightlessness.- An appropriate method of restraint shall be provided for a sleeping crew member.

4.2.7.3.2 Decompression Protection.- Space suits shall be provided for extra vehicular operations and in the event of cabin decompression. The same space suits shall be utilized for extra vehicular operations and cabin decompression emergencies. Mission reliability and crew safety requirements shall be satisfied without the use of space suits for cabin decompression. No beneficial effect on calculated reliability or crew safety shall be included in the analysis; nor shall there be any unrealistic compromise of Spacecraft systems imposed wholly by the use of space suits.

4.2.7.3.3 Sanitation

4.2.7.3.3.1 Human Waste.- The Command Module shall have a toilet for collection of urine and fecal waste. The toilet shall accomodate a single crewman. The toilet shall be placed in such a manner to permit use of temporary curtains or partitions for privacy. The collection system shall include means for disinfecting human waste sufficiently to render it harmless and unobjectional to the crew. All human waste shall be stored aboard the Spacecraft.

4.2.7.3.3.2 Personal Hygiene.- The Command Module shall be equipped with facilities for shaving, dental cleansing, bodily cleansing, and deodorizing. Facilities shall be included for cleansing of garments or for an appropriate number of garment changes.

4.2.7.3.3.3 Non-Human Waste.- The Command Module shall have provisions for handling of all other waste such as those from eating and personal hygiene.

4.2.7.3.3.4 Control of Infectious Germs.- The Spacecraft systems operation shall provide means for controlling infectious organisms which would have an unfavorable effect upon the crew members.

4.2.7.3.4 Food and Water

4.2.7.3.4.1 Food.- All food shall be of the dehydrated, freeze-dried or similar type that is reconstituted with water or does not require reconstitution. The food shall have a variety of flavor and texture similar to that provided in normal earth diets. There is no requirement for refrigerated storage; however, the foods shall require heating and chilling in preparation and service. The food items shall constitute a low bulk diet.

4.2.7.3.4.2 Water.- The primary source of potable water is from the fuel cell. In addition, sufficient water must be on board at launch to provide for the 72 hour landing requirement in event of early abort. Urine need not be recycled for potable water.

4.2.7.3.5 Emergency Equipment

4.2.7.3.5.1 Survival Equipment.- Post landing survival equipment shall include one three man life raft, food, location aids, first aid equipment and various accessories necessary to support the crew outside the Command Module for three days in any possible emergency landing area. Provisions shall be included for removing a three day water supply from the Command Module after landing; in addition, provisions shall be included for purifying a three day supply of sea water in event of water landing.

4.2.7.3.5.2 Personal Parachutes.- Each crewman shall be equipped with a personal parachute for use in event that the Command Module Landing System malfunctions, cannot function, or cannot cope with local hazards. The personal parachute shall be stowed in the back or seat of each couch; the restraint harness shall serve as the parachute harness.

4.2.7.3.5.3 First Aid Equipment.- The Command Module shall be equipped with first aid and preventive medicine items for coping with various human injuries and disorders. If feasible, Command Module first aid equipment may be integrated with survival equipment first aid items.

4.2.7.3.6 Radiation Dosimeters.- Each crew member shall be provided with an accurate, simply read, personal dosimeter system. The dosimeter system shall be worn or placed immediately adjacent to the crew members at all times. Each system shall measure cumulative dose, shall contain a warning device, and shall have an output plug for telementry signals.

4.2.7.3.7 Medical Instrumentation

4.2.7.3.7.1 Physiological Measurements.- Ultimate monitoring and telemetry requirements will be specified by NASA on the basis of early studies and operations. At this time it appears that the crew will perform all physiological monitoring of each other, except as noted below. Measurements shall be taken with simple, clinical devices; significant findings shall be reported by voice. One physiological parameter may be sensed automatically and telemetered periodically.

4.2.7.3.7.2 Early Orbital Missions. - During early Apollo orbital flights, a variety of biological instrumentation will be required to enhance crew safety and assess the crew's tolerance to long term weightlessness. During stressful periods of such early flights, the following data may be telemetered:

Electrocardiogram	2 channels
Blood pressure	Intermittently: shares ECG channels
Respiration rate and volume	1 channel
Body temperature	Commutated

During non-stress mission phases the above may be recorded intermittently on a programmed basis. Electroencephalography may also be required during non-stress phases. In addition to the above, various special physiological experiments will be performed in the Spacecraft as part of the NASA furnished scientific payload.

4.2.7.3.7.3 Extra-Vehicular Operations. - During manned extra-vehicular space suit operations, the following data shall be transmitted from the space suit and monitored within the Command Module voice, one physiological function (respiration, heartbeat, or electroencephalogram), and one to four environmental parameters (pressure, temperature, carbon dioxide, oxygen). The Command Module displays shall permit switching between and identification of simultaneously operating extra-vehicular suits.

4.2.7.3.8 Other Crew Equipment

4.2.7.3.8.1 Garments. - In addition to space suits, the crew shall be provided with garments for wear during normal mission phases. These garments shall be comfortable, close fitting, and free of areas that would snag on Command Module equipment. The garment must be wearable under the space suit. Each crewman shall be provided with a light weight cap to protect his head and eyes from injury as a result of collision with Spacecraft equipment. This cap may be separate from the space suit helmet.

4.2.7.3.8.2 Exercise.- Equipment shall be provided to permit the crew to exercise and maintain physical condition while in a weightless state.

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4.2.8 Environmental Control System.- The Command and Service Modules shall include the Environmental Control System which provides a conditioned, "shirtsleeve" atmosphere for the crew; provisions for space suits in event of cabin decompression; thermal control of all Command and Service Module eouipment where needed; and provisions for charging portable life support systems.

4.2.8.1 System Requirements. - The system requirements for the Environment Control System are as follows:

4.2.8.1.1 Metabolic.- The following conditions shall be provided by the Environmental Control System.

Total cabin pressure (O_2 and N_2 mixture) 7 ± 0.2 psia

Relative humidity 40 - 70%

Partial Pressure CO_2 - maximum 7.6 mm Hg

Temperature $75^{\circ} \pm 5^{\circ}$ F

4.2.8.1.2 Space Suit Operation . - The system shall provide for the use of individual space suits. In event of cabin decompression, the system shall provide a conditioned oxygen atmosphere at 3.5 psia to the space suits. The system must be capable of maintaining a cabin oxygen partial pressure of at least 3.5 psia for 5 minutes following a single one-half-inch diameter puncture in the pressure compartment in addition to the normal structural design criteria.

4.2.8.1.3 Equipment Cooling.- The system shall provide thermal control for equipment. No critical equipment shall depend upon the cabin atmosphere for cooling or depressurization.

4.2.8.2 System Description.- Environmental control is accomplished with two air loops, a gas supply system and a thermal control system. (See Fig 69.)

4.2.8.2.1 Air Loops

4.2.8.2.1.1. Regenerative Circuit Loop.- This loop supplies the conditioned atmosphere to the cabin and/or space suit.

4.2.8.2.1.1.1 Particulate Removal.- A debris trap shall be provided.

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4.2.8.2.1.1.2 Noxious Gases.- Noxious gases shall be removed by activated charcoal and a catalytic burner with the latter provided with a regenerative heat exchanger. A gas analyzer shall be provided.

4.2.8.2.1.1.3 Carbon Dioxide.- Carbon dioxide shall be absorbed by lithium hydroxide. The system shall provide for two parallel isolated lithium hydroxide canisters. The size of canisters and method of cartridge replacement shall be optimized.

4.2.8.2.1.1.4 Atmospheric Circulation.- The loop shall be provided with three parallel isolated blowers, any one of which will circulate the required flow. One operating blower shall be capable of supplying the following requirements to all three space suits simultaneously: Ventilation flow at 3.5 psia shall be 12 CFM thru each space suit; maximum flow resistance of each space suit shall be 5" of water. Each space suit connection shall have a bypass which will permit individual manual flow control.

4.2.8.2.1.1.5 Temperature Control.- A liquid coolant heat exchanger system shall be provided to cool the circulating air below the required dew point for condensate removal and humidity control. A regenerative heat exchanger shall be provided for the crew to control their inlet air temperature. A water evaporator shall also be provided for cooling of circulating air in event of loss of coolant.

4.2.8.2.1.1.6 Humidity Control.- The condensed water vapor shall be removed by either of two parallel isolated separators. Air driven centrifugal water separators shall be developed for use. The development of a sponge type water separator shall be pursued until the desired use of the centrifugal separator is unquestioned.

4.2.8.2.1.2 Cabin Loop.- The loop serves to provide cabin ventilation and thermal control during all phases of the mission and postlanding ventilation.

4.2.8.2.1.2.1 Atmospheric Circulation.- The loop shall be provided with two fans, either of which is capable of circulating the required flow and shall be designed to operate as an efficient exhaust fan during the post landing phase. Snorkels shall be provided for post landing.

4.2.8.2.1.2.2 Temperature Control.- A liquid coolant heat exchanger shall be provided to control cabin air temperature. It shall be designed to minimize fan power during the post landing phase.

4.2.8.2.2 Gas Supply System.- The primary gas supplies shall be stored as super critical cryogenics in the Service Module. Storage of these supplies is discussed in connection with the Electrical Power System.

4.2.8.2.2.1 Primary Gas Requirements.- The gas supply shall have a 50 percent excess capacity over that required for normal metabolic and leakage needs, plus two complete cabin repressurizations, and a minimum of 18 air lock operations.

Provisions shall be made for recharging portable life support systems.

4.2.8.2.2.2 Reentry Oxygen.- The Command Module shall contain a supply of gaseous oxygen in a high pressure bottle which shall be sufficient for reentry. A completely redundant system shall also be provided.

4.2.8.2.3 Thermal Control.- The normal dissipation of the internal thermal load of the Command Module is accomplished by absorbing heat with a circulating coolant and rejecting this heat from a space radiator during certain mission modes. Other cooling systems will supplement or relieve the primary system.

4.2.8.2.3.1 Radiator.- The space radiator shall be integral with the skin on the Service Module. For redundancy, dual coolant loops using radiator panels shall be provided. The radiator shall be designed to adequately meet the deep space random orientation condition. In addition, the radiator design shall be compatible with the water management program.

4.2.8.2.3.2 Coolant Loop.- The liquid coolant rejection transport fluid shall circulate through the regenerative circuit loop heat exchanger, electrical equipment cold plates, water evaporater gas storage heat exchanger, and the space radiator. Alternate liquid coolant passages in the equipment cold plates shall be provided. The liquid coolant flow shall be provided. The liquid coolant flow shall be maintained at fixed rate by one of three hermetically sealed, constant speed pumps. The redundant reservoir accumulator shall allow for a complete recharging of the liquid coolant. Provisions shall be made for a gas check before recharging in the event of a rupture to allow for isolation of leakage zones and to reestablish system integrity.

4.2.8.2.3.3 Mission Modes

4.2.8.2.3.3.1 Prelaunch (PAD).- Before lift off the space radiator shall be isolated and the total heat load dissipated by cooling the liquid coolant in the water evaporator with ground support freon.

4.2.8.2.3.3.2 Launch.- After lift off and attainment of sufficient altitude, water will be substituted in the evaporator for cooling.

4.2.8.2.3.3.3 Orbit.- The water evaporated in the liquid coolant loop may be used to supplement the radiator in earth and lunar orbit.

4.2.8.2.3.3.4 Transit.- The radiator shall be capable of dissipating the total heat load in spacecraft orientation during transit.

4.2.8.2.3.3.5 Reentry.- During reentry the thermal load shall be cooled by water evaporation in the liquid coolant heat exchanger. In event of liquid coolant loss, the metabolic heat load shall be cooled by a water evaporator in the regenerative suit circuit loop.

4.2.8.2.3.3.6 Extra-Vehicular Space Suit Operations. - The Environmental Control System shall not directly support space suits during extra-vehicular operations. During such operations, the space suits shall be supported by portable life support systems.

4.2.8.2.4 Controls.- Control of atmospheric pressures, humidity and temperature shall be automatic with provisions for manual surveillance and control.

4.2.8.3 Water Management.- Water shall be collected from the separator and the fuel cell and stored in positive expulsion tanks. The water collected from the fuel cells shall be stored separately and used as the primary source of potable water.

4.2.8.3.1 Water Requirements.- Water shall be provided at lift off to satisfy the crews postlanding metabolic needs and provide for evaporative cooling during exit and reentry following an immediate abort. A water management program shall be encompassed in the design to provide water requirements for all other phases of the mission.

4.2.8.4 Safety Features.- All relief valves, snorkel valves, and other valves which connect the internal pressure vessel to the space environment shall have manual closures and/or overrides. Filters shall be provided to protect all regulators, control valves, gas analyzers, etc. Relief valves shall be provided to prevent overpressurization of low pressure components. Flow limiting devices shall be provided to prevent excessive use of gas supplies and subsequent depletion of such supplies.

4.2.8.5 Preflight Checkout.- Fittings with proper access shall be provided to perform pressure checks, component performance tests, etc. during preflight checkout. This requirement is to preclude the necessity of breaking system integrity for component tests. Provisions shall be made for testing and calibrating all environmental sensors.

4.2.9. Electrical Power System

4.2.9.1 System Description

4.2.9.1.1 Purpose.- The Electrical Power System shall supply, regulate, and distribute all electrical power required by the Command and Service Module for the full duration of the mission, including the post landing recovery period.

4.2.9.1.2 Major Components.- The Electrical Power System shall be comprised of the following major components.

a. Three (3) non-regenerative hydrogen oxygen fuel cell modules.

b. Mechanical accessories, including control components, reactant tankage, piping, radiators, condensors, hydrogen circulators and water extractors, isolation valves and such other devices as required.

c. Three (3) silver zinc primary batteries, each having a nominal 28 volt output and a minimum capacity of 3000 watt hours (per battery) when discharged at the 10 hour rate at 80°F.

d. An Electrical Power System display and control panel, sufficient to monitor the operation and status of the system and for distribution of generated power to electrical loads, as required.

4.2.9.1.3 Location and Weight.- The location of each of the above components within the Spacecraft shall be as listed herein. Every effort shall be exercised to minimize equipment size and weight, commensurate with the established requirements and obtaining the highest practicable reliability.

Component	Location
Fuel cell module and controls	Service Module
Tanks (empty), Radiators, Heat exchangers, Piping, Valves	Service Module
Total Reactants, plus reserves	Service Module
Silver Zinc Batteries	Command Module
Electrical power distribution and controls	Command Module

4.2.9.1.4 Operating Modes

4.2.9.1.4.1 Normal Operation.- During all mission phases, from launch until reentry, the entire electrical power requirements of the Command and Service Module shall be supplied by the three fuel cell modules operating in parallel. The primary storage batteries would be maintained fully charged under this condition of operation.

4.2.9.1.4.2 Emergency Operation.- In the event of failure to one of the fuel cell modules the failed unit would be electrically and mechanically isolated from the system and the entire electrical load assumed by the two fuel cell modules remaining in operation. The primary batteries would be maintained fully charged under this condition of operation.

In the event of failure of two of the fuel cell modules, the failed units would be electrically and mechanically isolated from the system. Spacecraft electrical loads would be immediately reduced by the crew and manually programmed to hold within the generating capabilities of the remaining operable fuel cell module. The primary batteries would be recharged, if necessary, and maintained fully charged under this operating condition.

4.2.9.1.4.3 Reentry and Recovery.- At reentry, the fuel cell modules and accessories will be jettisoned. All subsequent electrical power requirements shall be provided by the primary storage batteries.

4.2.9.2 System Requirements

4.2.9.2.1 Fuel Cell Module.- Each fuel cell module shall have the following performance characteristics.

4.2.9.2.1.1 Type.- Fuel cell modules shall be of the low pressure intermediate temperature, Bacon type, utilizing porous nickel, unactivated electrodes and aqueous potassium hydroxide as the electrolyte. Fuel cells shall be operated non-regeneratively, utilizing hydrogen and oxygen as the reactants.

4.2.9.2.1.2 Output Power.- Each fuel cell module shall have a nominal capacity of 1200 watts at an output voltage of 28 volts and a current density conservatively assigned such that 50% overloads can be continuously supplied.

4.2.9.2.1.3 Pressure and Temperature.- The nominal cell operating pressure and temperature shall be approximately 60 psia and 425°F to 500°F respectively.

4.2.9.2.1.4 Fuel Consumption.- Under normal conditions of operation, the specific fuel consumption shall not exceed 0.9 lb/Kw-Hr, total H_2 and O_2.

4.2.9.2.1.5 Water Generation.- The water generated by the fuel cell module shall be potable and shall be separated from the hydrogen and stored.

4.2.9.2.1.6 Start Up.- Self sustaining reaction within the fuel cell module shall be initiated at a temperature of approximately 275°F. Integral heaters shall be provided to facilitate ground starting as well as during the mission. These heaters shall not be capable of heating units to excessive temperatures with the fuel cell and its cooling system inoperative.

4.2.9.2.1.7 Fuel Cell Modules.- A detection and control system shall be provided with each fuel cell module to prevent contamination of the collected water supply.

4.2.9.2.1.8 System Redundancy.- The degree of redundancy provided for mechanical and electrical accessory equipment such as radiator loops, control valves, piping circuits, voltage regulator, etc., shall, in general, be 100 percent.

4.2.9.2.2 Electrical Distribution

4.2.9.2.2.1 General.- The distribution portion of the electrical power system shall contain all necessary busses, wiring protective devices, switching and regulating equipment.

Except as specified herein, the electrical distribution system shall conform to the requirements of standard MIL-STD-704.

Selection of parts and materials, workmanship, fabrication and manufacturing processes shall be guided by the requirements of MIL E 5400, except as required to meet the performance or design requirement specified herein.

4.2.9.2.2.2 System Voltage.- Electrical power shall be generated and distributed at 28 volts DC (nominal).

4.2.9.2.2.3 Regulation.- The voltage level shall be regulated to prevent variance of more than ±2 volts from the nominal voltage under all conditions of operation of the fuel cell system.

4.2.9.2.2.4 AC Ripple.- All DC busses in the system shall be maintained essentially free of AC ripple (as defined by paragraph 3.12 of MIL-STD-704) to within a limit of 250 millivolts peak to peak.

4.2.9.2.2.5 Protection.- Busses and electrical loads shall be selectively protected such that individual load faults will not cause an interruption of power on the bus to which the load is connected. Likewise, a fault on the nonessential bus shall not cause an interruption of power to the essential bus.

4.2.9.2.2.6 Load Grouping.- All electrical loads supplied by the distribution system shall be classified as Essential, Nonessential, Pyrotechnic, or Recovery. Essential loads are defined as those loads (except pyrotechnic circuits) which are mandatory for safe return of the spacecraft to earth from any point in the lunar mission. Such loads as are not mandatory for safe return of the spacecraft shall be grouped on the Nonessential bus and provision made for disconnecting these loads as a group under emergency conditions. All loads required during the post landing recovery period shall be supplied by the Recovery bus and provision made for manually disconnecting this bus from the Essential bus following landing. Redundant busses shall be provided for pyrotechnic circuits, and used to supply only that type load.

4.2.9.2.2.7 Power Conversion.- Equipment which requires conversion of basic electrical power (28 volts DC) to power with other characteristics shall accept the basic power as defined herein for modification and use. Conversion or inversion devices required for this purpose shall be integral with the utilization system or utilization equipment, whenever practical.

4.2.9.2.2.8 External Power.- Provision shall be made to energize the distribution system from an external source (28 volts, 100 amps DC) through an umbilical connector and a blocking diode.

4.2.9.2.2.9 Electrical Distribution Panel.- The distribution panel shall be dead front and adequately enclosed or otherwise protected to minimize hazards to the crew and provide maximum mechanical protection for the electrical system and components. Switching and control shall be accomplished by manually operated circuit breakers or contactors in preference to electrically operated contactors, except where use of a remotely controlled device is necessary to reduce the length of large electrical conductors.

4.2.9.2.2.10 System Type.- The distribution system shall be a two wire grounded system, i.e., wire and busses shall be employed as the return path for electrical currents, in lieu of using the spacecraft structure for this purpose. The system negative shall be grounded at one point only and shall not be interrupted by any control or switching device.

4.2.9.2.3 Reactant Tankage

4.2.9.2.3.1 General Requirements.- Sufficient tankage shall be provided to store all reactants required by the fuel cell modules and environmental controls for a 14 day mission. Reactants shall be stored supercritically at cryogenic temperatures and the tankage shall consist of two equal volume storage vessels for each reactant. The main oxygen and nitrogen storage shall supply both the Environmental Controls System and the fuel cells.

4.2.9.2.3.2 Reserves.- The tankage volume shall include the fuel cell fluid requirements plus 10% reserve and the environmental fluid requirements. The hydrogen storage volume shall include the fuel cell requirements plus 10% reserve.

4.2.9.2.3.3 System Arrangement.- Adequate valves and controls shall be provided to isolate identical reactant tanks from each other, and from the environmental controls and

[redacted]

fuel cell modules. Valve arrangement shall allow flow from any reactant tank to any fuel cell module.

The schematic arrangement Figure 70 is intended only to convey to the vendor the requirements covered above, rather than the complete system arrangement.

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4.2.10 Communication and Operational Instrumentation System

4.2.10.1 System Requirements.- Equipment shall be constructed to facilitate maintenance by ground personnel and by the crew. Each system, together with the interconnecting cables, shall be as nearly self contained as possible to simplify removal from the Command and Service Module. The equipment and system shall be capable of sustained undergraded operation with supply voltage variation of +15 percent to -20 percent of the nominal bus voltage. Flexibility for incorporation of future additions or modifications shall be stressed throughout the design and assembly of all components and systems. Toward this end, the following features shall be provided:

a. Spare conductors shall be included in each wire group to permit system revisions or additions without necessitating retrunking of wire runs or additional bulkhead penetrations.

b. Insofar as possible, all spare contacts or relays, switches, contactors, etc., shall be wired and brought to an accessible point for future use, if needed.

A patch and programing panel shall be provided which will permit the routing of signal inputs from sensors to any selected signal conditioner and from these to any desired commutator channel. Panel design shall provide the capability of "repatching" during a mission.

4.2.10.1.2 Circuit Quality Analysis Chart.- The Contractor shall provide a circuit quality analysis for each radiating electrical system. The Contractor shall provide information showing exactly how ranging, telemetry, voice, and television data modulate all transmitters with which they are used. This information shall include:

a. Description of modulation systems used.

b. Bit rates used in each data mode.

c. Bandwidth required on subcarrier oscillators and main carrier.

d. Frequencies of all subcarrier oscillators and type of data on each.

4.2.10.2 Test and Maintenance.- The equipment and associated documentation shall be engineered for comprehensive and logical fault tracing. It shall be possible to check the operability of all functions of the equipment after installation in the Command and Service Modules. Each subsystem shall contain sufficient monitor points which are readily accessible to allow rapid and complete systems check. The equipment and systems shall be designed to facilitate prelaunch tests, before and after mating with the launch vehicle. Insofar as possible, the design shall provide for power control and system activation such that the maximum number of individual systems tests can be performed without full support or coordination with other Spacecraft systems or those of the launch vehicle. It is of prime importance that the coupling of test equipment does not affect the on-board systems so that unrealistic test conditions are created. The uncoupling of system connections and the introduction of test cabling shall be kept to a minimum. Consideration shall be given to flexible automatic checkout equipment.

4.2.10.3 Communication System.- The Command and Service Module Communications System shall provide the following:

Voice Communication
Telemetry
Television
Tracking Transponders
Radio Recovery Aids
Antenna Subsystems

The following systems descriptions are based upon GOSS utilization employing the currently supported HF, VHF, and C-band frequencies for near earth communications, and the UHF carrier frequency, using modulation techniques typical of the present DSIF system is contemplated for both near earth and lunar communications. The system design shall allow provision for this transition.

4.2.10.3.1 Voice Communication.- Two way voice communication capability between the individual crew members, between the Command Module and earth based stations, and between each module in a rendezvous maneuver shall be provided. A personal communication system shall provide two way voice communication between crew members whether internal or external to the Command Module. An intercommunication (plug-in) system shall be supplied. Reliable communication in the near earth phase of flight shall be afforded by a UHF link to that range at which DSIF communications can be acquired and maintained for all potential flight paths. Voice communication using the UHF DSIF transponder shall provide reliable voice transmission and reception to lunar distance.

4.2.10.3.2 Telemetry.- A flexible pulse code modulation telemetry subsystem compatible with both the VHF and UHF transmission systems shall be provided. Initial telemetry and display system design shall incorporate flexibility to add a ground spacecraft data link.

4.2.10.3.3 Television.- A television closed circuit subsystem for use by the crew in monitoring internal and external scenes in real time shall be provided. Optimum modulation method shall be employed. Frame rate and resolution trade-offs with transmitter power and antenna size shall be optimized.

4.2.10.3.4 Tracking Transponders.- A C-band transponder subsystem compatible with the AN/FPS-16 and equivalent radars shall be provided. This subsystem shall be capable of providing reliable tracking signals in the near earth phase of flight to that range at which DSIF tracking can be acquired and maintained for all potential flight paths. A UHF transponder providing reliable velocity and range tracking to lunar distance when used with the DSIF shall be supplied.

4.2.10.3.5 Radio Recovery Aids.- The radio recovery aids subsystem shall consist of an HF transceiver system which may be either voice or tone modulated, and a VHF beacon.

4.2.10.3.6 Antennas.- The near earth antenna system shall consist of multiple flush mouthed antennas which essentially provide omnidirectional patterns in a plane perpendicular to the booster longitudinal axis. A similar antenna compatible with DSIF shall be used at minor deep space distances. This antenna shall offer sufficient gain for reliable transfer of priority information at a reduced bandwidth in an emergency condition up to lunar distances. The directional antenna system shall be either designed for stresses encountered throughout the mission or be retractable for periods of high stress. Both manual and automatic antenna steering shall be provided for the directional antenna.

4.2.10.4 Operational Instrumentation

4.2.10.4.1 System Requirements.- The System Operational Instrumentation System shall detect, measure and display all parameters required by the crew for monitoring and evaluating the integrity and environment of the spacecraft and performance of the Spacecraft systems. It shall provide data for transmission to earth, to facilitate ground assessment of Spacecraft performance and failure analysis. It shall provide the crew with information as required for abort decision. In addition, the capability shall be provided for documenting the mission through photography and recording.

4.2.10.4.2 Measurements.- A tabulation of measurements shall be provided and include the number and type of all measurements; sensor characteristics; conditions when taken (flight, flight phase, etc.); data disposition, i.e., displayed, real time telemetry, recorded for telemetry playback, recorded for storage, etc. A block diagram showing the interrelationship of the instrumentation components shall also be provided.

4.2.10.4.3 Sensors.- The sensors selected for each application shall have an inherent reliability at least one order of magnitude greater than the measured and measuring subsystem and shall be compensated such that their capability to perform the intended function is not degraded by the environmental conditions to which they are subjected. Excitation voltage, where required, shall be standardized. Transducer output shall also be standardized, insofar as practicable. Inaccessible measurement areas shall be provided with both primary and spare sensors and associated auxiliary equipment as required. Electrical leads associated with the sensors shall be electrically shielded and mechanically secured so as to minimize the generation or pickup of noise by the leads.

4.2.10.4.4 Data Disposition.- The capability shall be provided for data transmission upon crew command or onboard programmed command (e.g., five minutes transmission each hour during the coast phase of the mission). Provisions shall be made for transmitting data in the following critical areas:

a. Measurements relating directly to conditions having an immediate effect on crew safety.

b. Sufficient measurements in each functional area or system to facilitate failure analysis in event of an unsuccessful flight.

c. Navigation and guidance data as required to permit ground station checking of vehicle position and course.

4.2.10.4.5 Tape Recorders.- One recorder system shall be provided for the storage of telemetry, voice, and possible video information for later playback at the discretion of the crew, or for data storage pending Spacecraft recovery. A second recorder system shall be provided for multi-channel recording of high frequency parameters such as sound and vibration. This recorder shall also be suitable for use in conjunction with the scientific and biomedical instruments.

4.2.10.4.6 Panel Display Indicators.- The panel display indicator shall not be coupled directly to those data channels which are providing similar information to the telemetry or recording system, i.e., there shall be no coupling between the panel display instruments and telemetry/recording channels which could result in cross effects between the circuits, even in event of malfunction.

4.2.10.4.7 Calibration.- A calibration feature shall be provided as an integral part of the measurement system and shall be such as to provide a rapid analytic assessment of the measurement system's performance. The method of calibration shall encompass the overall system where practicable, and in addition shall include selectivity of automatic or manual operation at the crew's discretion.

4.2.10.4.8 Clock.- Redudant, real time, binary code generating devices shall be provided to act as the primary time reference; to correlate all data; and to function as an integral part of all time critical operations. The accuracy and stability of the clock under the environmental conditions expected shall be compatible with the navigation and guidance requirements.

4.2.10.4.9 Telescope.- A gimbal mounted telescope shall be provided to aid in visual study and photography of the lunar surface and celestial bodies. Dual operating modes shall be possible (high power - narrow angle field of view, or low power - wide angle field of view). Reference axis information shall be provided.

4.2.10.4.10 Cameras.- Two onboard time correlated cameras shall be used on board; one suitable for monitoring the crew, displays, and spacecraft interior; the other suitable for lunar photography and stellar studies. The latter camera shall be capable of use in conjunction with the telescope or independent use at the crew's discretion.

4.3 Lunar Excursion Module Systems. - The characteristics of the major systems included in the Lunar Excursion Module are presented in the following paragraphs.

4.3.1 Guidance and Control System. - The Guidance and Control System is comprised of a Navigation and Guidance System and a Stabilization and Control System. The Navigation and Guidance System provides steering and thrust control signals for the Stabilization and Control System, Reaction Control System, and the Lunar Excursion Propulsion System. The Stabilization and Control System provides the attitude stabilization and maneuver control requirements.

4.3.1.1 Navigation and Guidance System

4.3.1.1.1 System Requirements. - The system requirements for the Navigation and Guidance System are as follows:

4.3.1.1.1.1 Abort. - The navigation and guidance required to abort from the lunar landing and return maneuvers at any phase and perform a rendezvous with the Command and Service Modules.

4.3.1.1.1.2 Lunar Orbit Transfer. - The navigation and guidance required to transfer from the circular orbit of the Command and Service Modules to an elliptical lunar orbit.

4.3.1.1.1.3 Lunar Landing. - The navigation and guidance required to land the Lunar Excursion Module on the lunar surface from the elliptical orbit including translation and hovering requirements.

4.3.1.1.1.4 Lunar Launch. - The navigation and guidance required to launch from the lunar surface into an elliptical lunar orbit.

4.3.1.1.1.5 Lunar Orbit Transfer and Rendezvous. - The navigation and guidance required to transfer from the elliptical orbit to the Command Service Modules circular orbit and perform the rendezvous maneuver.

4.3.1.1.1.6 Lunar Docking.- The navigation and guidance required to perform the docking maneuver with the Command and Service Modules.

4.3.1.1.2 System Description.- The Navigation and Guidance System shall consist of the following basic components:

Inertial measurement unit

Optical measurement unit

Range-drift measurement unit (Reticle)

Computer

Power and servo assembly

Control and display unit

Displays and controls

Cabling and junction box

Chart book and star catalog

Rendezvous radar and radar altimeter

The Navigation and Guidance System will be similar to the Navigation and Guidance System in the Command Module thereby allowing the possible use of the same components and/or spare parts in each of the separate systems where desirable.

4.3.1.2 Stabilization and Control System

4.3.1.2.1 System Requirements.- The system requirements for the Stabilization and Control System are as follows:

4.3.1.2.1.1 Abort.- The stabilization and control required during lunar aborts.

4.3.1.2.1.2 Lunar Orbit Transfer.- The stabilization and control required during the transfer from the circular orbit of the Command and Service Modules to an elliptical lunar orbit.

4.3.1.2.1.3 Lunar Landing. - The stabilization and control required to land the Lunar Excursion Module on the lunar surface from the elliptical orbit including translation and hovering requirements.

4.3.1.2.1.4 Lunar Launch. - The stabilization and control required to launch the Lunar Excursion Module from the lunar surface into an elliptical lunar orbit.

4.3.1.2.1.5 Lunar Orbit Transfer and Rendezvous. - The stabilization and control required to transfer from the elliptical orbit to the Command and Service Modules circular orbit and perform the rendezvous maneuver.

4.3.1.2.1.6 Lunar Docking. - The stabilization and control required to perform the docking with the Command and Service Modules.

4.3.1.2.2 System Description. - The Stabilization and Control System shall consist of the following basic components:

Attitude reference

Rate sensors

Control electronics assembly

Manual controls

Displays

Power supplies

Consideration shall be given to the desirability of a back-up Navigation and Guidance System utilizing elements of the Stabilization and Control System where possible. This system as a minimum shall include an attitude reference which will survive any combined maneuver which would cause the Navigation and Guidance System attitude reference to tumble.

4.3.2 Lunar Excursion Propulsion System

4.3.2.1 System Requirements. - The system requirements for the Lunar Excursion Propulsion System are as follows:

4.3.2.1.1 Abort. - The velocity increment required to perform abort maneuvers from any phase of the lunar landing and return flight.

4.3.2.1.2 Lunar Orbit Transfer. - The velocity increment required to transfer from the circular orbit of the Command and Service Modules to an elliptical lunar orbit.

4.2.2.1.3 Lunar Landing. - The velocity increment required to land the Lunar Excursion Module on the lunar surface from the elliptical orbit including translation and hovering requirements. The touchdown velocities shall not exceed a horizontal velocity of 5 ft/sec or a vertical velocity of 10 ft/sec.

4.3.2.1.4 Lunar Launch. - The velocity increment required to launch from the lunar surface into an elliptical lunar surface into an elliptical lunar orbit.

4.3.2.1.5 Lunar Orbit Transfer and Rendezvous. - The velocity increment required to transfer from the elliptical orbit to the Command and Service Modules circular orbit and perform the rendezvous maneuver.

4.3.2.2 System Description. - The Lunar Excursion Propulsion System will utilize earth storable hypergolic bipropellants and will have a pressurized propellant feed system. A single, partially, or two-stage propulsion system shall be designed to provide the most optimum system. Variable thrust will be required. Thrust vector control may be provided by gimbaling the engine or engines or by use of the Reaction Control System. If gimbaling is utilized, redundant gimbal actuation systems shall be provided. The minimum three sigma deviation of specific impulse during engine operating life shall not be less than $305 \frac{\text{lb-sec}}{\text{lb}}$.

4.3.2.2.1 Engines. - A single or multiple engine configuration shall be employed with consideration being given to providing maximum Lunar Excursion Module reliability. In designing the thrust chamber or chambers, consideration shall be given to designing for off normal conditions such as over pressure, transients, injector pluging, and streaking.

4.3.2.2.2 Pressurization Tank. - The propellant pressurization tank or tanks shall be sealed in a positive manner by redundant squib valves to prevent leakage prior to use.

4.3.2.2.3 Propellant Tanks. - The propellant tanks shall be equipped with a bladder for zero gravity expulsion. Bladders shall be capable of multiple cycling.

4.3.2.2.4 Propellant Utilization System. - A propellant utilization system to control proper oxider/fuel ratio shall be considered.

4.3.2.2.5 Variable Thrust System. - A variable area injector or upstream variable orificing shall be used to provide the variable thrust capability. The injector or orifice systems shall be designed to operate with maximum tolerance to system contamination without causing catastrophic failure of the system.

4.3.2.2.6 Propellants

4.3.2.2.6.1 Oxidizer. - The oxidizer shall be nitrogen tetroxide (N_2O_4) with nitrous oxide (N_2O) added to depress the freezing point if necessary.

4.3.2.2.6.2 Fuel. - The fuel shall be monamethylhydrazine (MMH) or a mixture of 50% hydrazine (N_2H_4) and 50% unsymmetrical dimethylhydrazine (UDMH).

4.3.3 Reaction Control System

4.3.3.1 System Requirements. - The system requirements for the Reaction Control System are as follows. It will be required to provide the impulse for attitude control and stabilization including periods when the Lunar Excursion Propulsion System is active unless gimbaling is employed. In addition, it shall also provide translational capability for terminal rendezvous and docking.

4.3.3.2 System Description. - The Reaction Control System shall consist of two independent, interconnectable subsystems, each capable of meeting the total torque and impulse requirements. Each subsystem shall provide two directional control about all axes. The Reaction Control System shall be pulse modulated.

4.3.3.2.1 Thrust Chambers. - The thrust chambers shall be radiation cooled.

4.3.3.2.2 Propellant Tanks. - Each subsystem shall have one oxidizer and one fuel tank. Each tank shall be equipped with a bladder for zero gravity expulsion. Bladders shall be capable of multiple cycling.

4.3.3.2.3 Propellant Feed System. - Normally the pair of propellant tanks in each subsystem shall feed all thrust chambers in that particular subsystem. However, reversible isolation valves shall be furnished to allow isolation of the thrust chambers in each axis. Reversible valves shall be furnished to allow propellant feed from the Lunar Excursion Propulsion System. In these redundant modes of propellant feed, quad check valves shall be utilized to prevent transfer of propellants from one subsystem to the other subsystem tankage or to the propulsion system.

4.3.3.2.4 Pressurization. - Each subsystem shall have a gaseous helium storage and pressurization system. Quad check valves shall be used at each propellant tank feed. Redundant squib valves shall be used to isolate the high pressure storage until the system operation is required; however, provisions shall be made for ground servicing and checkout.

4.3.3.2.5 Propellants. - The same propellant combination as used for the Lunar Excursion Propulsion System shall be utilized in the Reaction Control System.

4.3.4 Lunar Touchdown System

4.3.4.1 System Requirements. - The system requirements for the Lunar Touchdown System are as follows:

4.3.4.1.1 Landing Impact Attenuation. - The Lunar Touchdown System will provide the impact attenuation required to land the Lunar Excursion Module on the lunar surface.

4.3.4.1.2 Post Landing Attitude. - The Lunar Touchdown System will be required to land the Lunar Excursion Module in a near vertical position satisfactory for lunar launch and normal egress.

4.3.4.2 System Description

4.3.4.2.1 Structural Load Paths. - The Lunar Touchdown System will be attached to the Lunar Excursion Module by hard points which will accommodate variations of landing gear geometries and have load distribution capabilities compatible with anticipated landing gear loads.

4.3.4.2.2 Interference with Other Systems. - The Lunar Touchdown System shall be designed such that in all positions of stowage and deployment it does not interfere with the use of the Lunar Excursion Propulsion System or Reaction Control System.

4.3.4.2.3 Deployment. - The Lunar Touchdown System will normally be deployed from within the Spacecraft; however, deployment may be performed manually by the crew in space suits outside the Spacecraft.

4.3.4.2.4 Inspection, Maintenance, and Servicing. - The design shall be such that advantage may be taken of the crew's capabilities outside the Lunar Excursion Module both during flight and on the lunar surface for inspection, maintenance, and servicing.

4.3.4.2.5 Lunar Landing Aids. - The deployment of landing aids from the Lunar Excursion Module, such as penetrometers, at near the hover altitude should be considered.

4.3.5 Structural System. - In addition to the fundamental load carrying structures, the Lunar Excursion Module structural system shall include meteroid protection and radiation protection inherent in the structure. Primary structures shall be designed and evaluated in accordance with standard aircraft practice and in accordance with the design criteria section.

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4.3.6 Crew System. - The Crew System consists of the Flight Crew and Crew Equipment System.

4.3.6.1 Flight Crew. - The Commander and the Systems Engineer will comprise the Lunar Excursion Module Flight Crew.

4.3.6.1.1 Crew Integration. - The crew work space arrangement shall reflect the onboard command and control responsibilities of the crew and provide for active onboard management of the spacecraft subsystems.

4.3.6.1.2 Displays and Controls. - The displays and controls shall provide maximum crew effectiveness and Spacecraft reliability. Division of crew tasks shall be reflected in the displays and controls arrangement. Location of all displays and controls shall not require either crewman to be mobile during the lunar landing or launch phases of the mission.

4.3.6.1.3 Manual Control. - All manual controls which are subject to inadvertant actuation during crew ingress and egress shall be provided with locks or guards. Such safety devices shall not degrade the reliability of the control system or crew performance.

4.3.6.1.4 Operation by Single Crew Member. - Controls and displays shall be arranged to permit one crew member to return the Lunar Excursion Module safely to the Command Module; however, this requirement shall not cause degraded reliability or crew performance for two man operation.

4.3.6.2 Crew Equipment System

4.3.6.2.1 System Requirement. - The Crew Equipment System will be required to provide the crew with the necessary acceleration protection, restraint, food and water, and other crew equipment. It will also include space suits and portable life support systems for use both within and outside the Lunar Excursion Module.

4.3.6.2.2 System Description

4.3.6.2.2.1 Seat. - Each crewman shall be provided with a seat capable of supporting against acceleration loads. The seat shall be adjustable to provide for a comfortable rest position and for rendezvous and docking visibility.

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4.3.6.2.2.2 Restraint System. - A restraint system shall be provided with each seat. It shall provide adequate restraint for all flight phases.

4.3.6.2.2.3 Food and Water. - The food provided shall constitute a low bulk diet and shall be of dehydrated, freeze dried, or similar type. There will be no requirement for refrigeration. Water required for both consumption and vehicle cooling shall be provided within the Lunar Excursion Module prior to separation from the Command Module.

4.3.6.2.2.4 First Aid Equipment. - The Lunar Excursion Module shall be equipped with first aid and preventive medicine for coping with various human injuries and disorders.

4.3.6.2.2.5 Space Suits. - An unpressurized space suit shall be worn by each crew member during normal inter vehicular operation. This same space suit will be utilized during extra vehicular operations and when the cabin is decompressed either under normal egress and ingress, or emergency conditions.

4.3.6.2.2.6 Portable Life Support System. - The portable life support system shall be used with the space suits during extra vehicular operations. A separate system shall be provided for each crew member. This system shall be of the recirculating type. It shall be capable of supporting a crewman for four hours independent of the Lunar Excursion Module, and will be capable of being recharged. It shall include the communications transceiver which will be used by the crewmen while outside the Lunar Excursion Module. During lunar exploration or manned extra vehicular operations, the following data shall be transmitted and monitored within the Lunar Excursion Module; voice, one physiological function (respiration, heart beat, or electronecephalogram) and one to four environmental parameters (pressure, temperature, carbon dioxide, oxygen).

4.3.6.2.2.7 Personal Radiation Dosimeters. - Each crew member shall be provided with an accurate, simply read, personal dosimeter system. The dosimeter shall be worn or placed immediately adjacent to the crew member at all times. Each dosimeter shall measure accumulative dose, shall contain a warning device, and shall have an output plug for telemetry signals.

4.3.7 Environmental Control System

4.3.7.1 System Requirements. - The Environmental Control System shall provide an unpressurized space suit environment, provisions for space suits, thermal control of all Lunar Excursion Module Equipment where needed, and provisions for recharging the portable life support systems. It will allow the crew to open their face plates and remove their gloves during normal operations. In the event of decompression, the crew shall close their face plates and continue operations unimpeded. The Environmental Control System shall meet the requirements imposed by egress and ingress. The following conditions shall be provided by the environmental control system:

Total Cabin Pressure	(O_2) 5 ± 0.2 psia
Relative Humidity	40 - 70%
Carbon Dioxide Partial Pressure (Maximum)	7.6 mm Hg
Temperature	$75^\circ \pm 5^\circ$F

In the event of emergency cabin decompression, the system shall provide a conditioned oxygen atmosphere at 3.5 psia to the space suits. The system must be capable of maintaining a cabin pressure of at least 3.5 psia for two minutes following a single 1/2 inch diameter puncture in the pressurized compartment.

4.3.7.2 System Description

4.3.7.2.1 Oxygen Supply. - The oxygen supply shall be supercritical; however, the system will be serviced with liquid oxygen with allowances for passive heating until just prior to separation in lunar orbit. Prior to separation additional heat will be furnished by electrical heaters to assure supercritical pressure.

4.3.7.2.2 Circulation. - The Environmental Control System shall be provided with three parallel isolated blowers, any one of which will circulate the required flow. Any one blower shall be capable of supplying the requirements of both pressure suits simultaneously assuming; ventilation flow at 3.5 psia will be 12 cfm through each suit and the maximum flow resistance of each suit will be 5 inches of water. Each space suit connection shall have a by-pass which will permit individual manual flow control.

4.3.7.2.3 Carbon Dioxide and Odor Control. - Carbon dioxide and odor control will be provided by lithium hydroxide and activated charcoal, respectively.

4.3.7.2.4 Noxious Gas Control. - Noxious gases including ozone, methane, hydrogen, carbon monoxide, freon, or other gases emitted from over-heated equipment shall be removed to maintain a safe working environment.

4.3.7.2.5 Temperature Control. - A liquid coolant heat exchanger system shall be provided to cool the circulating air below the required dew point for condensate removal and humidity control. A regenerative heat exchanger shall be provided for the crew to control their inlet air temperature. A water evaporator shall also be provided for cooling or circulating air in the event of loss of coolant.

4.3.7.2.6 Thermal Control System. - Passive cooling shall be utilized where possible. An analysis shall be made to determine the optimum method of heat rejection. Expendable refrigeration using water in a recirculating radiator system should be considered with final selection commensurate with reliability and weight requirements. Systems, subsystems, and components critical to the completion of the mission shall not be solely dependent on the cabin atmosphere for heat rejection. Studies should include a water management analysis incorporating the Command and Service Modules Systems.

4.3.7.2.7 Humidity Control. - The condensed water vapor shall be removed by either of two parallel isolated separators. Air-driven centrifugal water separators shall be developed for use. The development of a sponge type water separator shall be pursued until the desired use of the centrifugal separator is unquestioned.

4.3.7.2.8 Partical Removal. - A debris trap shall be provided to remove particals from the Environmental Control System.

4.3.8 Electrical Power System

4.3.8.1 System Requirements. - The Electrical Power System shall supply, regulate and distribute all electrical power required by the Lunar Excursion Module.

4.3.8.2 System Description. - Consideration shall be given to matching the electrical characteristics of the Lunar Excursion Module power system to that of the Command and Service Modules. The source of electrical power will depend largely on the time contingency allowed for the various mission events, particularly during rendezvous maneuvers. Possible power sources are silver-zinc batteries, chemical dynamic engines using hypergolic fuels and hydrogen-oxygen power systems. Consideration shall be given to the desirability of utilizing reactants for the power system which are the same as onboard propellants. Consideration shall also be given to overall system simplicity where other reactants are employed, such as hydrogen and oxygen systems. The selection shall be based on considerations of mission profiles, reliability goals, development programs and evidence of tangible weight advantages.

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4.3.9 Communication System

4.3.9.1 System Requirements. - The system requirements for the Communication System are as follows:

4.3.9.1.1 Voice Communication. - The Communication System will provide the capability of voice communication between:

a. The Lunar Excursion Module and Command Module during line-of-sight phases of the mission.

b. The Lunar Excursion Module and the earth, thereby extending the range of communication link between the Lunar Excursion Module and Command Module.

c. The Lunar Excursion Module and a crew member at a radial distance of up to 3 nautical miles from the Lunar Excursion Module.

d. The crew members within the Lunar Excursion Module.

4.3.9.1.2 Telemetry. - The Communication System shall provide the capability of data transmission on either a time shared basis with the voice or transmitted simultaneously with voice. This system will be used to transmit the data obtained from the operational instrumentation system as required.

4.3.9.1.3 Television. - The Communication System shall include a portable near commercial quality television subsystem capable of real time and high resolution picture transmission. Consideration shall be given to providing television transmission of the Lunar Excursion Module launch utilizing this system. A closed circuit television subsystem for use by the crew in monitoring the internal and external scenes in real time shall also be provided.

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4.3.9.2 System Description. - The Communication System shall consist of the following basic components:

Intercommunication System

VHF Transceiver

UHF Transceiver

Telemetry System

Television System

Antennas

4.3.10 Instrumentation System. - The Instrumentation System is comprised of an Operational Instrumentation System, a Flight Research and Development Instrumentation System, and a Scientific Instrumentation System.

4.3.10.1 Operational Instrumentational System

4.3.10.1.1 System Requirements. - The Operational Instrumentational System shall detect, measure, and display all data required by the crew for monitoring and evaluating the integrity and environment of the Lunar Excursion Module and performance of the Lunar Excursion Module systems. In addition, the capability shall be provided for documenting the mission through photography and recording. It shall also provide data for transmission to earth, to facilitate ground assessment of Lunar Excursion Module performance and failure analysis.

4.3.10.1.2 System Description. - The Operational Instrumentation System shall consist of the following basic components.

4.3.10.1.2.1 Clock. - A real-time digital clock shall be provided to act as the Lunar Excursion Module time reference; to correlate all data; function as an integral part of all time-critical operations; drive displays; and synchronize other Lunar Excursion Module equipments. Accuracy requirements shall be established by non-guidance equipment. This clock shall be synchronized to the Navigation and Guidance System clock. Circuit redundancy shall be incorporated to the extend required to insure reliability.

4.3.10.1.2.2 Tape Recorder System. - A tape recorder system shall be provided for the storage of telemetry, voice, and possible video information for later playback at the discretion of the crew, or for data storage. This recorder system shall also be suitable for use in conjunction with the Scientific Instrumentation System.

4.3.10.1.2.3 Display and Control System. - The display and control system shall not be coupled directly to those data channels which are providing similar information to the telemetry or recording system, i.e., there shall be no coupling between the panel display instruments and telemetry recording channels which could result in cross effects between the circuits.

4.3.10.1.2.4 Sensors.- The sensors selected for each application shall have an inherent reliability at least one order of magnitude greater than the measured and measuring subsystem and shall be compensated such that the capability to perform the intended function is not degraded by the environmental conditions to which they are subjected. Excitation voltage where required, shall be standardized, in so far as practical. In inaccessible measurement areas both primary and spare sensors and associated auxiliary equipment shall be provided as required. Electrical leads associated with sensors shall be electrically shielded and mechanically secured so as to minimize the generation or pick up of noise by the leads.

4.3.10.1.2.5 Calibration System.- A calibration system shall be provided as an integral part of the measurement system and shall be such as to provide a rapid analytic assessment of the measurement systems performance.

4.3.10.1.2.6 Cameras.- One still and two motion picture cameras shall be provided in the Lunar Excursion Module. The still camera shall be capable of high resolution photography of the lunar surface and will be used for studies outside the Lunar Excursion Module. Accessories shall include a telephoto lens. This camera will be suitable for use with the microscopic equipment provided as a part of the Scientific Instrumentation System. The two motion picture cameras shall be capable of onboard photography. In addition, one will be used to document the movement of the crew on the lunar surface and the other will be suitable for use outside the Lunar Excursion Module.

4.3.10.1.2.7 Telescope.- A gimble mounted telescope shall be provided to aid the visual studies and photography of the lunar surface and celestial bodies. This telescope shall be suitable for use with the still camera provided above and will provide a camera-telescope configuration capable of infared and ultraviolet photography. Dual operating modes shall be provided (high power-narrow angle field of view or low power-wide angle field of view). Reference axes information shall be provided.

4.3.10.2 Flight Research and Development Instrumentation System

4.3.10.2.1 System Requirements. - The Flight Research and Development Instrumentation System will provide for the measurement and the display, recording, and/or telemetry of all parameters required in the development of the Lunar Excursion Module.

4.3.10.2.2 System Description. - The Flight Research and Development System shall consist of the following basic components:

Telemetry Systems (including transmitters)

Clock and Tape Recorder System

Sensors and Signal Conditioning

Calibration System

Power Supply

Radar Transponder System

Antennas

4.3.10.3 Scientific Instrumentation System

4.3.10.3.1 System Requirements. - The Scientific Instrumentation System will provide primarily for selenologic research. This instrumentation should be suitable for use either inside or outside the vehicle as deemed necessary. Provision should be made for storing data and/or scientific packages in the Lunar Excursion Module. All items considered to be nonessential for the safe return of the vehicle should be discarded prior to lunar launch. The scientific instrumentation system will utilize the lunar Excursion Module Operational Instrumentation System where possible.

4.3.10.3.2 System Description

4.3.10.3.2.1 Lunar Atmosphere Analyser. - This instrument shall provide the capability of determining the qualitative and quantitative chemical composition of the lunar atmosphere. This instrument may be used as the backup system for the cabin atmosphere partial pressure sensing system; otherwise it will be jettisoned prior to lunar launch.

4.3.10.3.2.2 Gravitometer. - This instrument shall provide the capability for determining the direction and magnitude of the moon's gravitational field at the lunar surface.

4.3.10.3.2.3 Magnetometer. - This instrument shall provide the capability for determining the direction and magnitude of the lunar magnetic field.

4.3.10.3.2.4 Radiation Spectrometer. - This instrument shall provide the capability of determining the radiation spectrum at the lunar surface.

4.3.10.3.2.5 Specimen Return Container. - This shall consist of a small container to be filled with lunar material. The container shall seal in a manner such that no material gas, solid, or bacteria can enter the container on the return flight.

4.3.10.3.2.6 Rock and Soil Analysis Equipment. - This equipment shall provide for obtaining samples of the lunar surface material, for obtaining core samples, and for the analysis of these samples by means of a microscope and other analysis equipment. The microscope shall be capable of being attached to the still camera provided in the Operational Instrumentation System. Coreing equipment will be integrated into the seismographic equipment as the source of excitation or as a means of placing a charge below the surface after coreing is completed.

4.3.10.3.2.7 Seismographic Equipment. - This instrument shall provide the capability for investigating the subsurface structure of the moon.

4.3.10.3.2.8 Soil Temperature Instrument. - This instrument shall provide the capability for measuring lunar surface and subsurface temperatures.

5.0 Mission Control Center (MCC) and Ground Operational Support System (GOSS). - The design configuration of the Mission Control Center and the ultimate design configuration of the Ground Operational Support System have not yet been established. This section describes the operational concept for the Mission Control Center and the computational facilities, gives a general description of the initial configuration of the Ground Operational Support System, and a general outline of the ultimate configuration as currently visualized. Existing facilities such as the Mercury network and the DSIF, both appropriately modified, will probably be used in the Apollo program.

5.1 General Description. - Overall control of all Apollo support elements throughout all phases of a mission will be accomplished from a Mission Control Center (MCC). Mission launch activities up to the time of liftoff will be conducted from a launch control center, at Cape Canaveral. In addition to the launch control center, two types of remote stations will be used. The first type of station will provide support for the following communications: voice, telemetry reception and data processing, data transmission from the ground to the Spacecraft, tracking to determine Spacecraft position and velocity with appropriate data processing and an acquisition system for antenna pointing. Initially the ground support for earth orbital flights will be supported by modified Mercury type stations to support the diversified use of frequencies in the VHF and C-Bands, with the contemplated use of the DSIF UHF frequency band for lunar distance communications. It is visualized that eventually some of the Mercury type sites will be modified or new sites will be implemented to operate using a unified UHF frequency which will support all voice, telemetry, television, and ranging information for near earth and lunar distances. In the proposed unified concept antenna changes will be required at the existing Mercury sites to enable those sites to have both near earth and lunar distance capabilities. However, the DSIF would have no role in the near earth and earth orbital missions. The second type of remote station will be equipped for use in tracking the Command Module during reentry. Some new stations will probably be required, particularly to provide tracking during reentry. These stations will be located both on land and on ships. The remote stations will be connected to the communications and computation

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centers located in the Mission Control Center by landlines, submarine cables, and/or by radio depending on the location of the remote stations. A station will be located at the NASA Manned Spacecraft Center at Houston. This station may be used for Spacecraft-GOSS equipment compatibility checks, simulated missions, astronaut-ground procedure training, development of network operational procedures, as well as for actual missions

5.1.1 Mission Control Center. - The Mission Control Center will have the capability of monitoring the Spacecraft and directing the support elements for all phases of Apollo missions including unmanned and manned earth-orbital and translunar flights. In addition, this control center will include the simulation and training facilities associated with the Spacecraft and the GOSS. These simulation and training facilities include the Apollo crew trainer coupled into the Mission Control Center and simulated remote stations located adjacent to the Mission Control Center. This will combine crew and Mission Control Center personnel training and procedural development.

The Mission Control Center will include a communications center and the appropriate data processing equipment and displays required to allow complete and adequate control of the mission information flow. The Mission Control Center will also include the computing facilities that will be required to handle the data processing required for the determination of vehicle position and velocity and other associated computations throughout the flight phase of the mission.

The information flow associated with the Mission Control Center will include voice communication capability to and from the Spacecraft via relay through any of the remote stations, the transmission of information to the Spacecraft (this may be direct commands for unmanned Spacecraft or for assimilation by the crew of manned Spacecraft), the reception of processed vehicle telemetry data from the GOSS stations, the control and conduct of the GOSS, and all tracking and tracking support data.

5.1.2 Launch Control Center. - Launch control, including space vehicle preparation and checkouts, and the launch countdown will be conducted from Cape Canaveral. Launch control center facilities include the displays and communications necessary for monitoring of the progress of the mission countdown and powered flight phase.

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5.1.3 Remote Station.- The ground transmitted signal will include voice (relayed from MCC if desired), coded information and beacon or transponder interrogation. The Spacecraft transmission and subsequent ground systems reception will include voice, down telemetry, and beacon or transponder response. It is anticipated that as the program advances the RF link between the Spacecraft and the GOSS may transgress from initial HF, VHF and C-Band links to a single UHF link. The basic site equipment includes an automatic data processor which controls the information flow through the site. Where suitable point-to point communication circuits exist, the voice information is relayed to the MCC. The telemetry and tracking information is recorded on tape units and simultaneously fed into the data processor where the information is selected by established ground rules and/or MCC directives.

The site data processor, in addition to accepting and reprocessing telemetry and tracking data, also deals with information received from the MCC and from the local inputs and delivers it to acquisition consoles, TTY and higher-speed data transmission systems, and to local visual displays.

Acquisition methods and aids will be provided for acquiring the Spacecraft in angle, frequency, and range. Simulation aids for local training and exercises will be provided for the RF systems and for the communication components. Each of the remote ground stations with the exception of the reentry may eventually be capable of a significant communications and tracking capability at lunar distances. Thus, loss of any station is not catastrophic since alternative lunar capability will exist at other stations.

An interim period will exist before the achievement of the contemplated GOSS for Apollo from the current ground equipment employing Verlort and AN/FPS-16 radars, FM/FM VHF telemetry and UHF voice. The transition from the Mercury type of equipment to the unified frequency system-equipment should be made consistent with the Apollo systems development and the Apollo program schedules. The current system will remain substantially unchanged if project schedules for the early Apollo vehicles must carry extensions of the Mercury System.

5.1.4 Remote Station Equipment.- Current equipment plans for each ground station includes the use of UHF and VHF

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communications systems, the use of C-band equipment for near earth tracking, and the use of UHF transponders for tracking at lunar distances. The unified RF systems concept utilizes a single UHF frequency for both near earth and lunar communications and tracking.

The unified systems concept requires that the RF modulation techniques used in a single RF UHF carrier bandwidth will be the same for both earth orbital and lunar missions. The remote station configuration provides an antenna installation supporting two RF information channels (not widely separated) in the same frequency band. These information channels would be used for position and velocity determination, voice, and telemetry. The functional layout of the remote site is shown in figure 71, and figure 72 indicates the type and kinds of data flow that occur in the site.

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APPENDIX B

INSTRUCTIONS AND REQUIREMENTS FOR PHOTOGRAPHIC DOCUMENTATION

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INSTRUCTIONS AND REQUIREMENTS FOR PHOTOGRAPHIC DOCUMENTATION

1. PHOTOGRAPHY.- The Contractor shall accomplish still and/or motion picture photography on both a continuing and an "as negotiated" basis as indicated herein. Photographic coverage shall include documentation of highlight aspects of research and development, facilities construction and utilization, hardware fabrication and production, ground test activities, including rapid sequence and high speed engineering sequential motion picture coverage of appropriate test phases, and related events and subjects involving the Contractor's area of responsibility.

2. OBJECTIVE.- The objective of the photographic coverage specified herein is to satisfy a continuing NASA MSC need for documentation and reporting of the Contractors research and development activities and progress. The still and/or motion picture coverage thus obtained will be used for purposes of program evaluation and management analysis, written report backup, and the preparation of training, orientation, and briefing films. Other uses include legal, historical, and the fulfillment of various information services requirements.

3. STANDARDIZATION. - For purposes of compatibility and in the interest of economy in reproduction, it is necessary to standardize in the type of original films used by the various producers and contractors. For normal motion picture photography (16 mm, 24 f.p.s.) Eastman Ektachrome Commercial type 7255, or equivalent, is recommended. When light conditions prevent the use of this film, Ektachrome ER type 7257 (daylight), or Ektachrome ER type 7258 (tungsten), or equivalent, may be used. These high-speed emulsions (ASA 160-120) should be used only when absolutely necessary, as some quality losses result in duplication.

4. GENERAL MOTION PICTURE AND STILL PHOTOGRAPHIC SPECIFICATIONS.- These instructions outline specifications for motion picture photography and the still picture documentation required. Changes to these specifications may be made only with the approval of the Contracting Officer.

a. Motion picture specifications:

(1) As a general rule, original motion picture photography shall be in 16 mm Ektachrome commercial, or equivalent, exposed at 24 frames per second. The use of 35 mm color film must be specifically authorized by the Contracting Officer. Black-and-

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white film and other frame rates may be used in instances where the capability of the color film or the normal frame rates would be detrimental to the accomplishment of specialized photographic coverage, such as aerial, engineering sequential, and time measurement photography.

(2) The Contractor shall not project or cut original film exposed in connection with the Contract, except to eliminate waste film caused by camera failure or faulty photographic techniques (gross over or underexposure, over or underdevelopment, out of focus, etc.) which results in qualitatively unsatisfactory film. Unusable heads and tails of scenes and unselected takes may be retained by the Contractor on file or destroyed at the Contractor's discretion.

(3) All original camera film footage shall be slated whenever possible. Slate information shall include, as appropriate: Contractor identification, project number and/or name, Contract number, security classification, date photographed, scene and take number. Two copies of caption information describing the action involved in each scene and the significance of the sequence of which the individual scene is a part, shall be forwarded with all original camera film footage submitted to the NASA-Manned Spacecraft Center, Apollo Spacecraft Project Office. All individual reels of film footage will bear head and tail security classification leaders.

b. Still Picture Specifications:
All still photography will be of professional quality and in a quantity that will meet the needs of both the NASA and the Contractor for scientific, technical and reporting data required in support of the assigned research and development effort.

(1) As a general rule, the still photography shall be accomplished on 4 x 5 inch black and white film, 4 x 5 inch negative or reversible color film may be used in those instances where it is deemed essential to record and present the subject matter distinctly and accurately and for significant highlight events such as roll outs, mockups, etc. The original camera raw stock film shall be of a type determined by the contractor to be best suited to the recording objective under the prevailing environmental conditions of each photographic assignment.

(2) The following data shall be lettered in ink on the clear margin of each original negative or color transparency on the acetate side starting from the left: negative number, date, contractor, and classification.

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(a) The negative number: This shall start with numeral 1 (one) for the first photograph of the calendar year on each specific contract of which the photographic coverage is a part.

(b) The date shall consist of numerals for the day of the month, followed by the abbreviated name of the month followed by the last numerals of the calendar year.

(c) Contractor's and subcontractors' name if applicable, abbreviated, shall follow the date of photography.

(d) If the photograph is classified, the classification shall follow the contractor's name. A typical negative marking would be as follows: 120/14 JUL 62 (Contractor's name)/Confidential.

(e) Each negative or color equivalent shall be placed in a separate negative preserver. A contact print of the negative shall be attached to the front of the envelope (to assure minimum handling of the negative). The negative identification data shall be marked on the preserver, starting in the top left front corner. In addition the preserver shall be conspicuously marked with the proper classification in accordance with DOD Industrial Security Manual, Section II, Handling of Classified Information.

(f) A written caption shall be prepared for each negative produced and forwarded under terms of this Contract. This information must include the who, what, when, where, and why type of data as well as other pertinent facts, including the specific date the photograph was taken. If nicknames are used, explain their meaning. The caption may be typed on a sheet of paper and placed inside the negative preserver, or attached to the back of the envelope. The captions shall be double spaced.

(g) The negative identification data specified above shall be reproduced on all prints made. This reproduction may be accomplished by any means available which will insure a permanent record of the identification data on each print, such as: photographic reproduction through the negative; by typing, waterproof ink lettering, ditto, or rubber stamp. In addition to the identification data, the front of each classified print shall be stamped with the appropriate classification (in the white border) at the top and bottom and on the back.

5. MOTION PICTURE REQUIREMENTS:

a. Documentation.- The Contractor will accomplish motion picture coverage of significant highlight events within the area of his activity, as they occur, and which are essential to the fulfillment of the NASA MSC's need for engineering, evaluation, and Management data, or for reporting purposes. This coverage will include the unsuccessful and unfavorable events as well as the positive aspects of the Contractor's activity and progress.

b. Film Clips.- The Contractor shall accomplish additional motion picture coverage as required for the preparation of film clips as directed by the MSC Apollo Spacecraft Project Office. Subject matter of this film footage will include coverage of special happenings such as mockups, development test activities, and other events which depict the program progress and status. Footage suitable for use in the various NASA MSC film reports must portray a complete story of a specific research and development event, phase, or activity. The photographic coverage should include a variety of scenes of the reported item or event, i.e., establishing shots, medium shots, close ups, and cutaways, to assist the NASA film editor in telling the story. The film footage should consist of full length, unedited, untitled, silent scenes of sufficient length to provide 5-10 minutes running time as received from the Contractor.

c. Special Film Requirements.- The production of briefing, concept, indoctrination films, and special animation sequences may be assigned to the Contractor from time to time by the Contracting Officer. The production of these special film reports will be subject to contract negotiation.

6. STILL PHOTOGRAPHIC REQUIREMENTS.- The Contractor shall accomplish still photographic documentation of all significant highlight events within the area of his activity and responsibility as they occur and as he determines is essential to the fulfillment of MSC's and the Contractor's need for engineering, evaluation, management data, and reporting purposes. "Special Interest" highlight events shall be accomplished in color as specified in paragraph 4(b). Routine documentation will be done in black and white.

7. TRANSMITTAL OF PHOTOGRAPHIC MATERIALS:

a. Motion Picture Film

(1) All of the original motion picture footage produced and costed under terms of this Contract, is the property of

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the NASA. Unless otherwise specified, the Contractor will forward all original motion picture material produced under this Contract to NASA Manned Spacecraft Center, Apollo Spacecraft Project Office. Written information describing the activities and items shown in the film will accompany each shipment of film.

(2) When the Contractor produces films other than those specified and/or requested by the Contracting Officer, utilizing film footage exposed and costed under this Contract, it shall be at no expense to NASA. When such films are used for public release purposes by the Contractor, they shall be reviewed by and receive final approval in writing from NASA Manned Spacecraft Center before being released for exhibition. Requests for release of such Contractor sponsored films, including a viewing print of each, will be forwarded to the Apollo Spacecraft Project Office, NASA Manned Spacecraft Center.

(3). All classified motion picture film footage and completed film reports produced under this Contract shall be handled in accordance with the provisions of DOD Industrial Security Manual, Section II, Handling of Classified Information. The original film and two prints which are made from the original and which match frame for frame will be submitted. In addition, two copies of written information describing the activities, and items shown in the film footage, will be forwarded by the Contractor to the NASA Manned Spacecraft Center, Apollo Spacecraft Project Office.

b. Still Pictures.

(1) The black and white or color negative or color transparency, together with a contact print (of the black and white negative only) and two 8-1/2 x 11" enlargements of the black and white negative shall be forwarded to the MSC Apollo Spacecraft Project Office.

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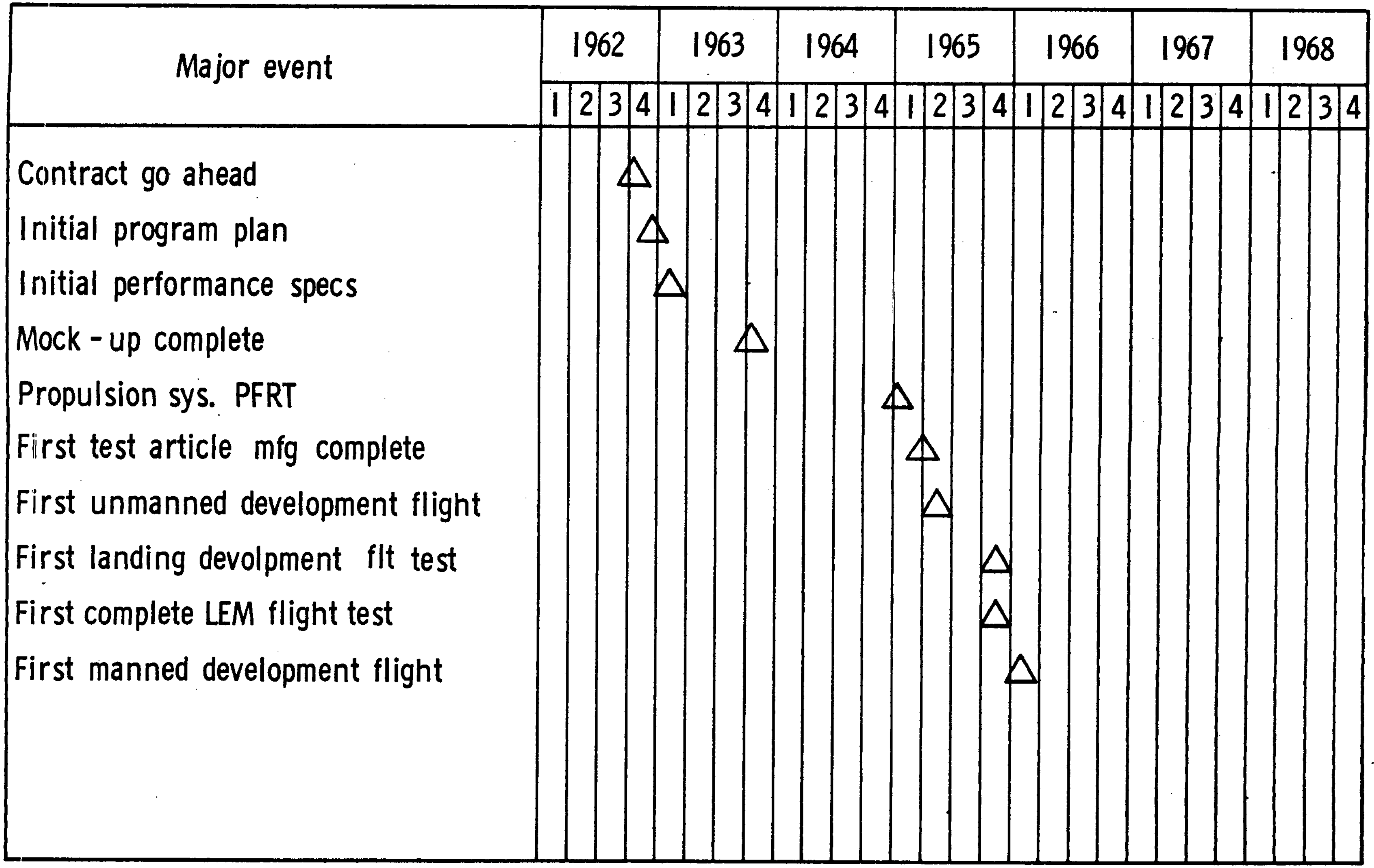

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Table I Lunar excursion module master phasing schedule

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TABLE II DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery* (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.1.2	Document Revision Methods	1	As required	I	5** 20***
4.5.2.1.1	Ground Support Equipment Performance and Interface Specifications	2	As required	I	50** 100***
4.5.2.1.2	Lunar Excursion Module Subsystem Specifications	4	As required	I	50** 100***
4.5.2.1.3	Material, Parts, and Process Specifications	15 days	As required	II (New Specs) III (Existing Specs)	50
4.5.2.1.4	Mockup Specifications	2	As required	I	50** 50**
4.5.2.1.5	Training Equipment Specifications	4	As required	I	50** 100***
4.5.2.1.6	Final Specifications	6 months after completion of all other technical contractural requirements		I	5** 1*** (reproducible)

* Initial delivery requirements are shown as time after date of contract, unless otherwise noted.
** Prior to NASA approval.
*** Subsequent to NASA approval.

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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues of Revisions	Documentation Type	Approximate No. of Copies
4.5.3.1.1	Program Plan	2	As required	I	100** 200***
4.5.3.1.2	Facilities Plan	2	As required	I NASA approval required prior to implementation	50** 100***
4.5.3.1.3	Test Plan	2	As required	I	50** 100***
4.5.3.1.4	Manufacturing Plan	2	As required	I	50** 100***
4.5.3.1.5	Part I: Reliability Program Plan	2	As required	I	50** 100***
	Part II:Reliability Test Plan	2	As required	I	50** 100***
4.5.3.1.6	Quality Program Plan	2	As required	II	50
4.5.3.1.7	Maintenance Plan	2	As required	I	50** 100***
4.5.3.1.8	Support Plan	2	As required	I	50** 100***
4.5.3.1.9	Training Plan	2	As required	I	50** 100***
4.5.3.1.10	End Item Test Plan	5	As required	I	50** 100***

** Prior to NASA approval
*** Subsequent to NASA approval

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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.3.2	PERT Reports	As required	Biweekly	II	1 (TWX)
4.5.3.2.1	Pert Event and Activities Description Document	2	As required	II	100
4.5.3.3	Monthly Financial Management Reports	10 days after end of first month	10 days after end of each interim month; 15 days after end of each quarter	II	25
4.5.3.4	Hardware List	1	As required	I	50** 100***
4.5.3.5	Mockup Inspection Plan	4	As required	I	25** 50***
4.5.3.6	Interface Documents	3	As required	I	10** 20***
4.5.4.1	Monthly Progress Report	10 days after end of first month	10 days after end of month for first two months of each calendar quarter	II	100
4.5.4.2	Quarterly Progress Reports	10 days after end of first calendar quarter	10 days after end of each calendar quarter	II	100

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*** Subsequent to NASA approval

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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.4.3	Final Report	6 months after completion of all other technical contractual requirements		II	5 (1 reproducible)
4.5.4.4	Weekly Launch Site Activities Reports	2 days after end of first week of operation at launch site	2 days after end of each week	II	100
4.5.4.5	Monthly Weight and Balance Reports	10 days after end of first month	10 days after end of each month	II	50
4.5.4.6	Emergency Action Reports	As required		II	20
4.5.4.7	Quarterly Reliability Status Report	1 month after end of first calendar quarter	1 month after end of each calendar quarter	II	20
4.5.4.8	Still Photographs	Contractor: 12 days after exposure, submitted weekly. Subcontractors: 20 days after exposure, submitted weekly		II	1 B/W Print Negative 2 ea. $8\frac{1}{2}$x11" enlargements

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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.4.9	Motion Picture Photography				
	Documentation	Contractor: 20 days after shooting * Subcontractor: 30 days after shooting *		II	Original plus 2 prints
	Film Clips	15 days after completion of shooting		II	Original plus 2 prints
4.5.4.10	Lunar Excursion Module Flight Reports	1 month after each flight	-	I	50** 200***
4.5.4.11	Lunar Excursion Module Equipment Status Report	12	As required	II	10
4.5.4.12	Program Management Plan Reports				
	a. Milestones	6 weeks	Every 12 weeks	I	20** 50***
	b. Schedule Dates	12 weeks	Biweekly on Wednesday	II	1 (TWX)

* Certain film footage exposed for engineering sequential and metric data purposes may be held longer than the days specified with written notification including anticipated delivery date.
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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.5.1	Technical Data, Reports and Analyses	2 weeks after completion of each block of effort or logical subdivisions thereof	-	II	20
4.5.5.2	Design Information	As required	-	II	20
4.5.5.3	Materials Reports	1 month after end of second calendar quarter	Subsequent Reports 1 month after every other calendar quarter. Final report 2 months after completion of the work for the final period of the contract	II	20
4.5.6.1	Qualification Status List	6	As required	I	20
4.5.6.2	Qualification Test Reports and Data	1 month after each test series		II(Reports) III(Data)	20
4.5.6.3	Failure Data	5 days after failure	As required	II	2
4.5.6.4	Monthly Failure Summary	10 days after sixth month	10 days after end of each month	II	10

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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues of Revisions	Documentation Type	Approximate No. of Copies
4.5.7.1	Acceptance Test Data Sheets	15 days after each test series	-	II(Major Components) III (all others)	20
4.5.7.2	Data and Reports on other Tests	1 month after each test or test series	-	II(Reports) III(Data)	10
4.5.7.3	Special Sampling Plans	1 month prior to use	As required	II	5** 10
4.5.7.4	Results of Special Measuring and Test Equipment Evaluations	1 month prior to use	As required	II	10
4.5.7.5	Monthly Quality Status Report	10 days after end of twelfth month	10 days after end of each month	II	20
4.5.7.6	Quarterly Summaries of Quality Program Performance Audits	15 days after end of fourth quarter	15 days after end of each calendar quarter	II	20

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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.7.7	Test and Inspection Procedures	1 month prior to each test series	-	II	20
4.5.7.8	End-Item Test and Inspection Procedures	1 month prior to each test series	-	I	20
4.5.7.9	Process Control Procedures	2 weeks prior to intended use	As required	II	20
4.5.7.10	Storage Procedures for End Items	2 weeks prior to intended use	As required	II	20
4.5.7.11	Application of Sampling Plans	2 weeks prior to intended use	As required	II	20
4.5.8	Drawings	As requested	As requested	II	As requested
4.5.8.2	Final Drawings	6 months after completion of all other technical contractual requirements		II	1(Microfilm)
4.5.8.4	Drawing List	3	Biweekly	II	20
4.5.9.1	Checkout Manuals	6	As required	I	20** 50***
4.5.9.2	Lunar Excursion Module Operations Manuals	6	As required	I	20** 50***

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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.9.3	Lunar Excursion Module Flight Operation Manuals	6	As required	I	50** 100***
4.5.9.4	Maintenance and Repair Manuals	6	As required	I	20** 50***
4.5.9.5	Lunar Excursion Module Familiarization Manual	4	As required	I	50** 250***
4.5.9.6	Ground Support Equipment Manuals	6	As required	I	50** 100***
4.5.9.7	Description Manuals	4 months prior to each launch	As required	II	100
4.5.9.8	Transportation and Handling Manuals	6	As required	I	20** 50***
4.5.9.9	Training Manuals	6	As required	I	50** 100***

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*** Subsequent to NASA approval

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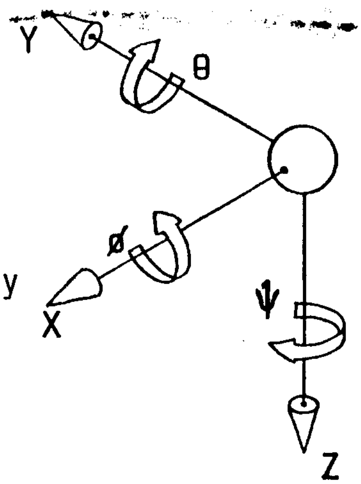
Positive directions of axes and angles (forces and moments) are shown by arrows. (when launch vehicle is at a launch angle of 90°, the positive "X" direction in vertically upwards.)



Axis		Moment about axis		
Designation	Sym-bol	Designation	Sym-bol	Positive direction
Longitudinal	X	Rolling	L	Y ⟶ Z
Lateral	Y	Pitching	M	Z ⟶ X
Normal	Z	Yawing	N	X ⟶ Y

Force (parallel to axis) symbol	Angle		Velocities	
	Designation	Sym-bol	Linear (compo-nent along axis)	Angular
X	Roll	ø	u	p
Y	Pitch	θ	v	q
Z	Yaw	ψ	w	r

Figure 1.- Reference axis system.

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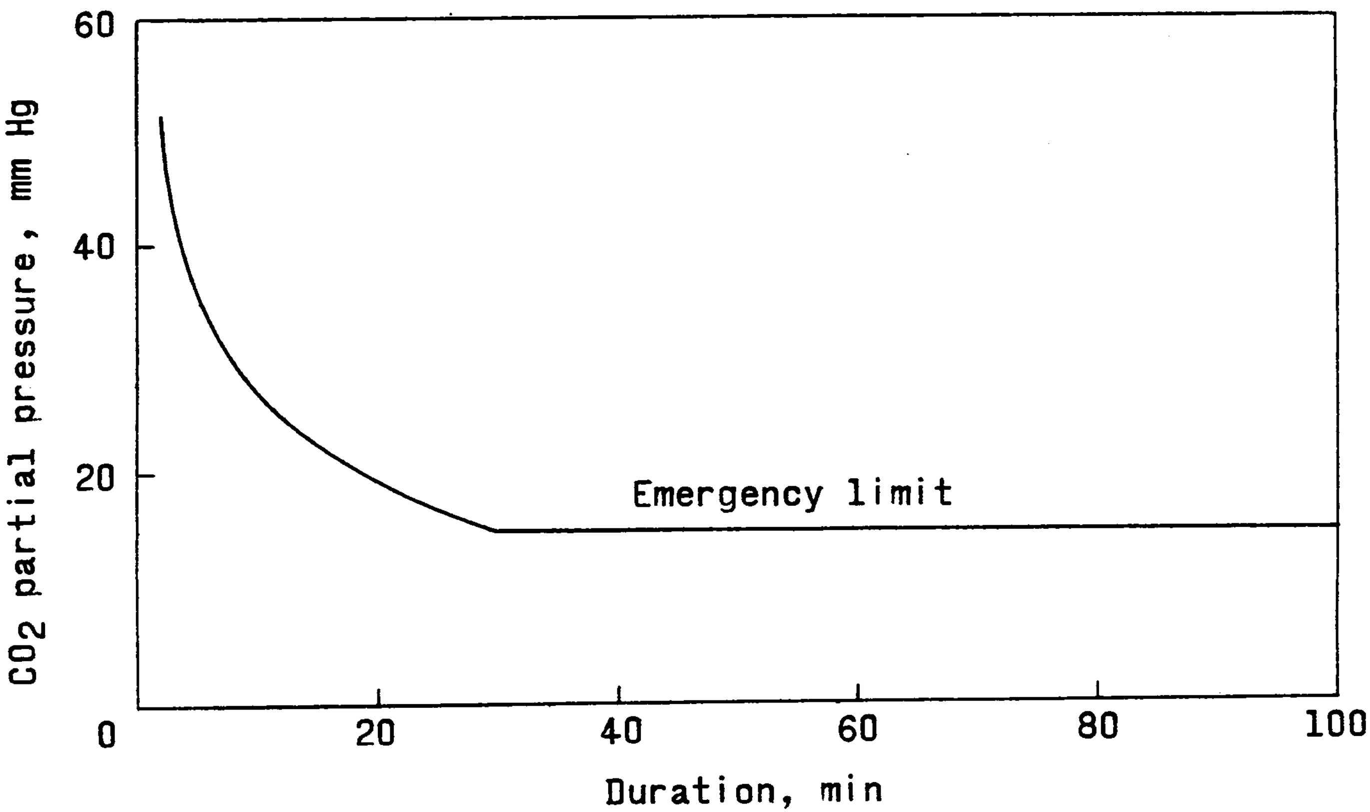

Figure 2.- Emergency carbon dioxide limit.

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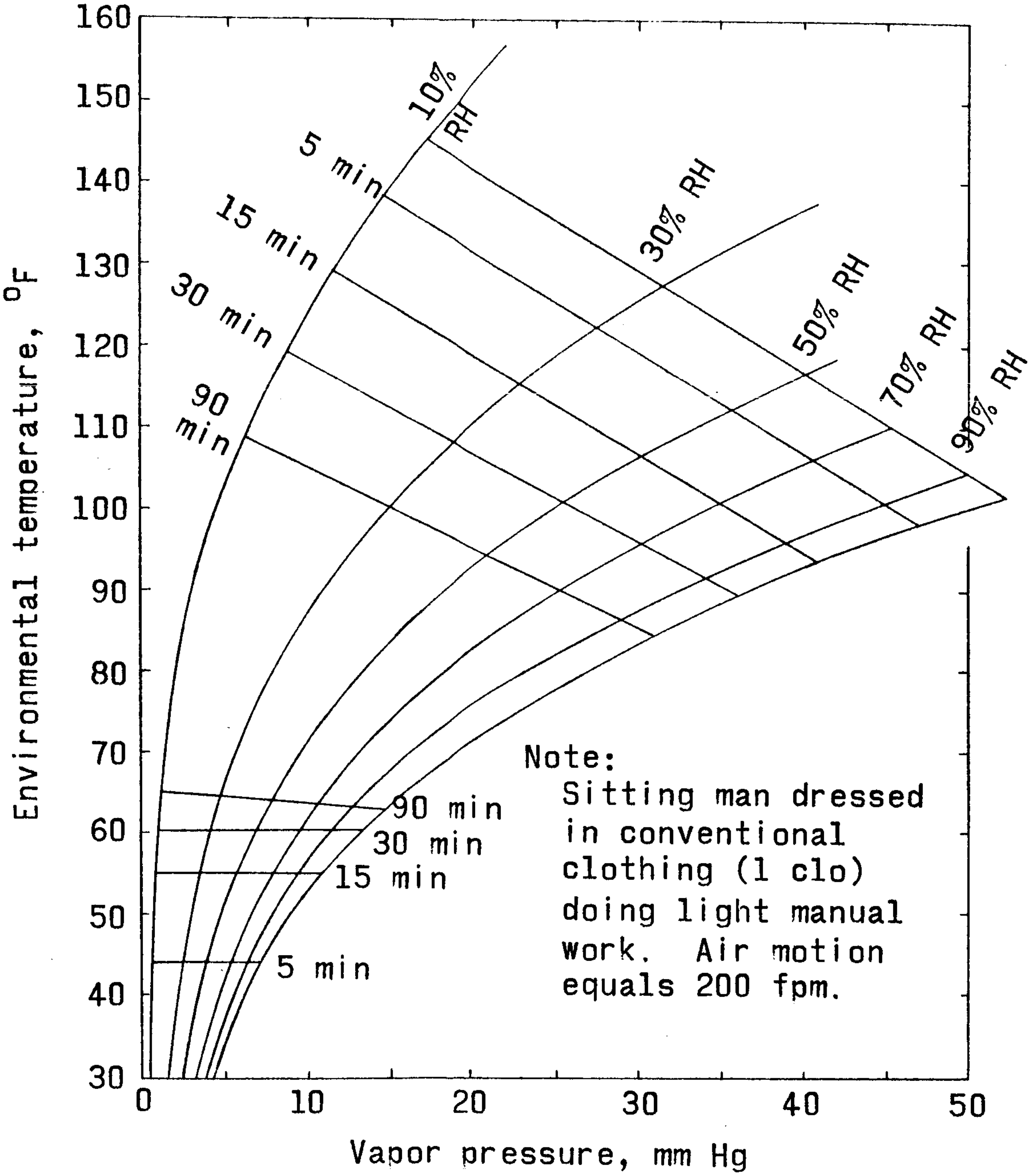

Figure 3.- Temperature and humidity nominal limit.

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[redacted]

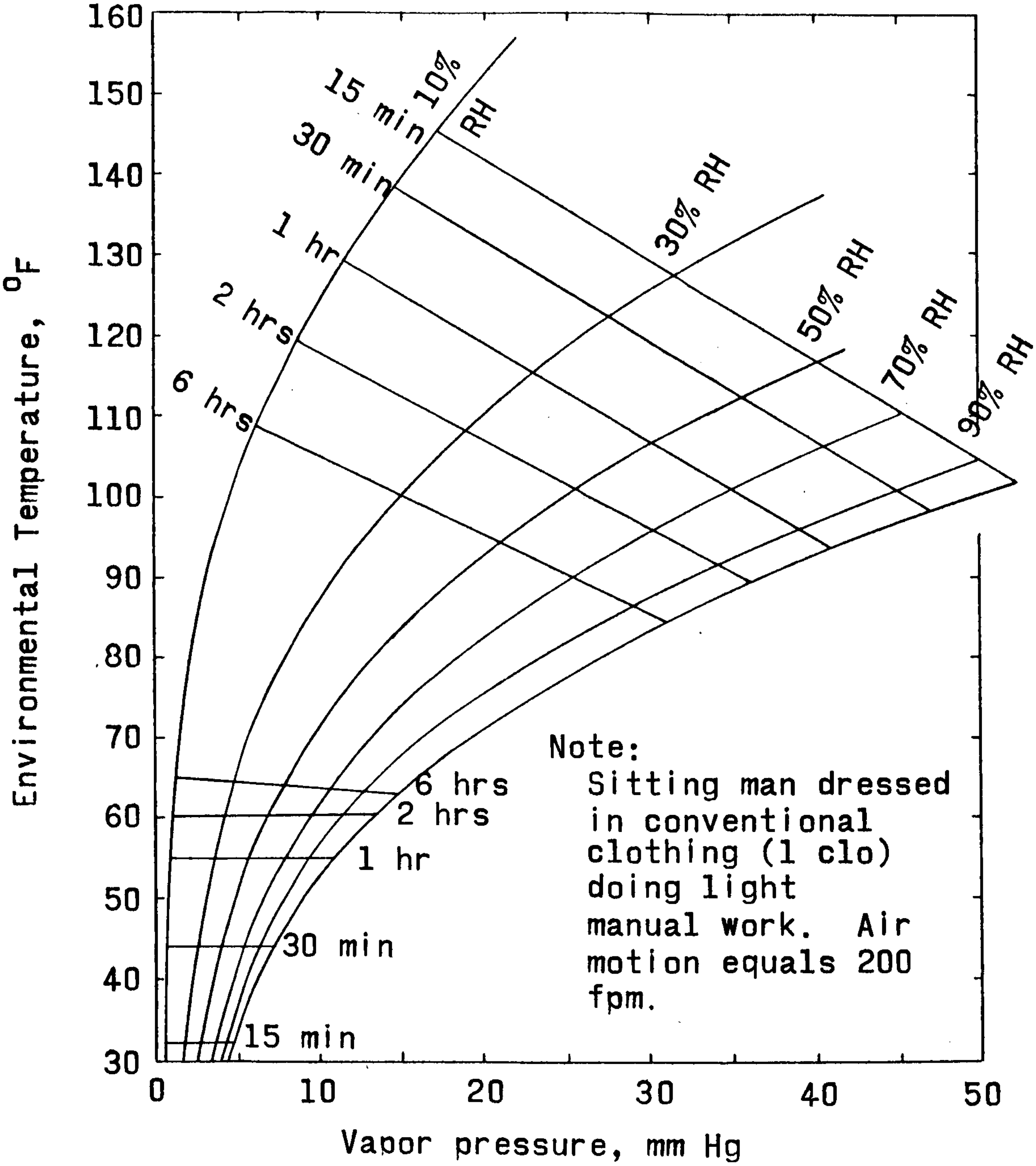

Figure 4.- Temperature and humidity emergency limit.

[redacted]

Critical organ	Maximum permissible integrated dose (rem)	RBE (rem rad)	Average yearly dose (rad)	Maximum permissible single acute emergency exposure (rad)	Location of dose point *
Skin of whole body	1,630	1.4	233	500[1]	0.07-mm depth from surface of cylinder 2 at highest dose rate point along eyeline
Blood-forming organs	271	1.0	54	200	5-cm depth from surface of cylinder 2
Feet, ankles, and hands	3,910	1.4	559	700[2]	0.07-mm depth from surface of cylinder 8 at highest dose point
Eyes	271	2[3]	27	100	3-mm depth from surface on cylinder 1 along eyeline

*See figure 6.

1 Based on skin erythema level

2 Based on skin erythema level but these appendages believed to be less radiosensitive

3 Slightly higher RBE assumed since eyes are believed more radiosensitive

Figure 5.- Radiation exposure limits.

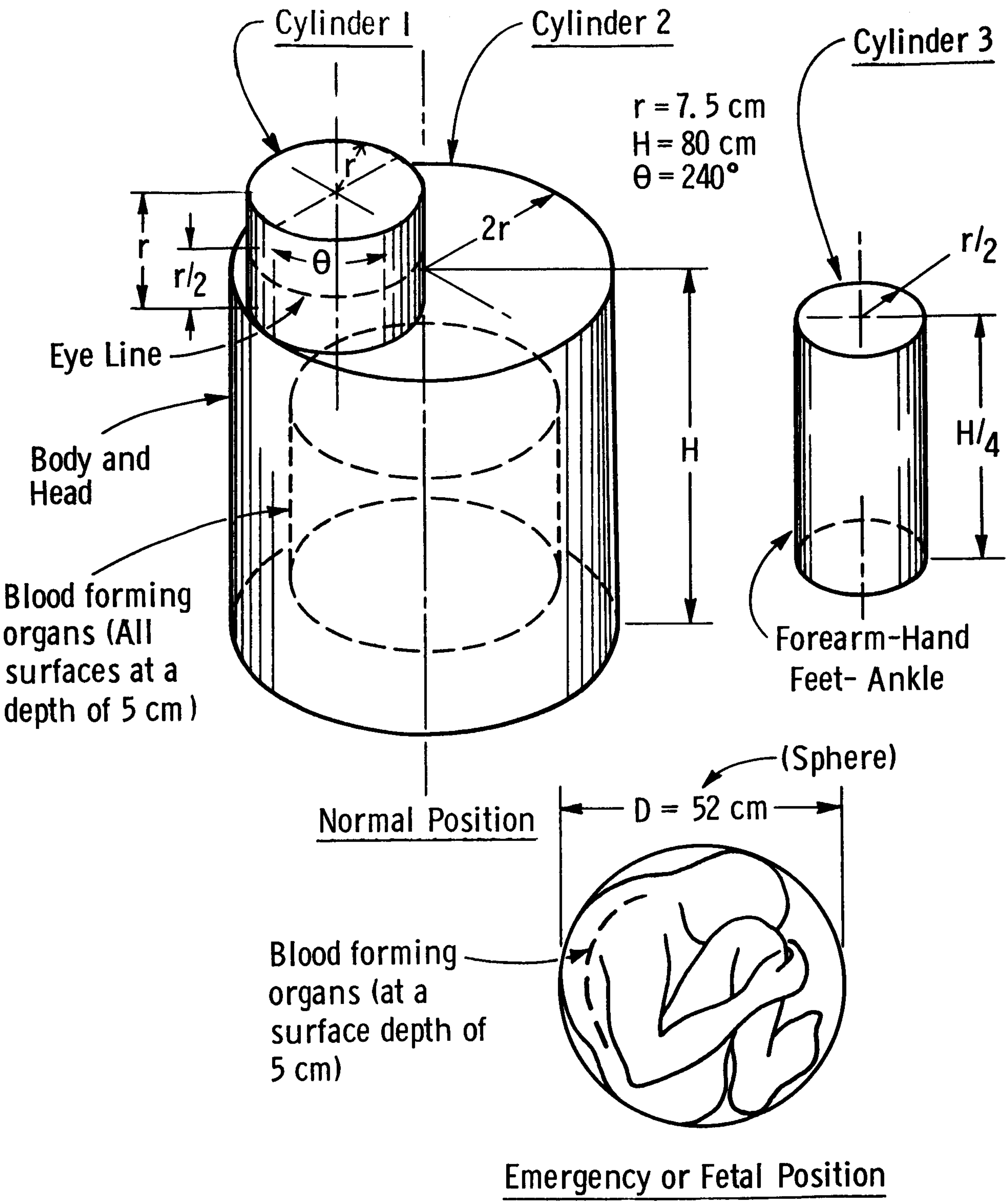

Figure 6. - Models of the radiation standard man.

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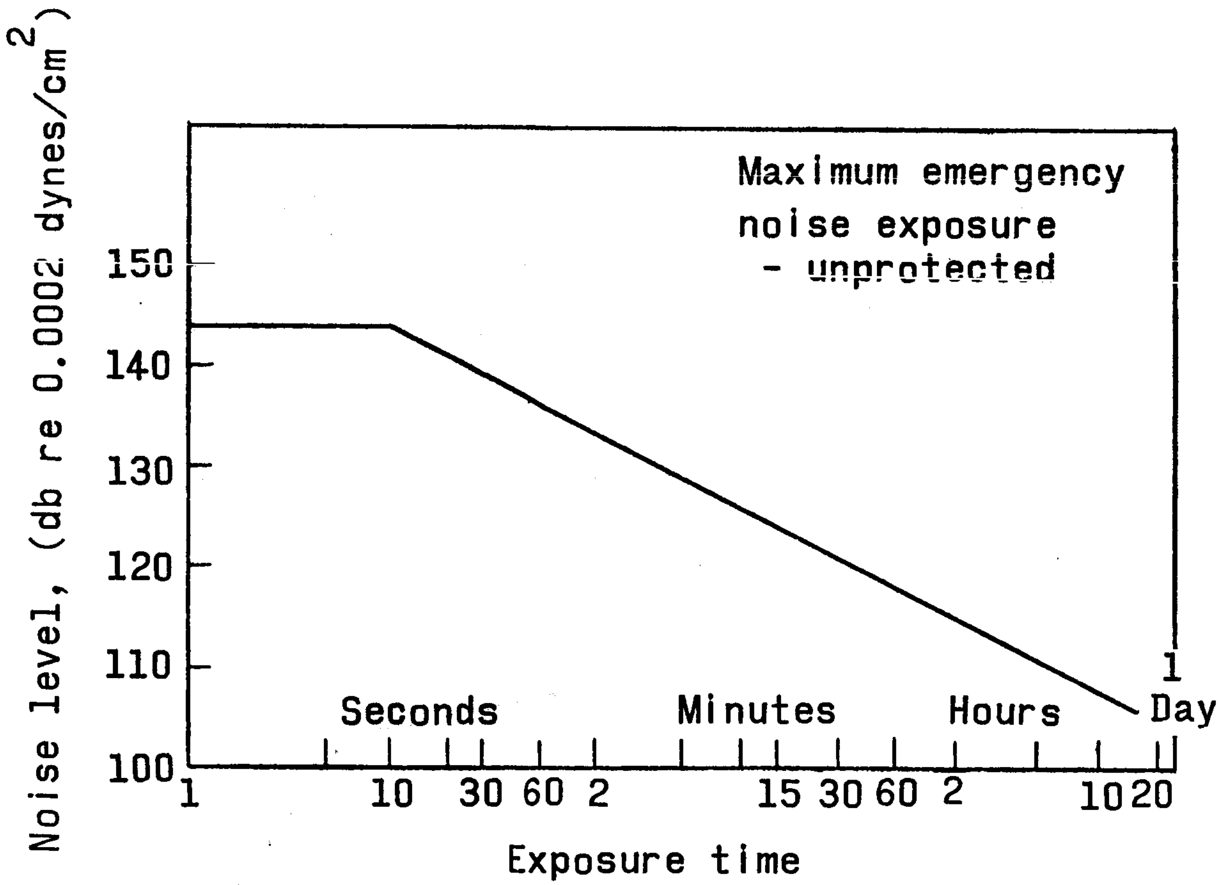

Figure 7 .- Noise tolerance, emergency limit.

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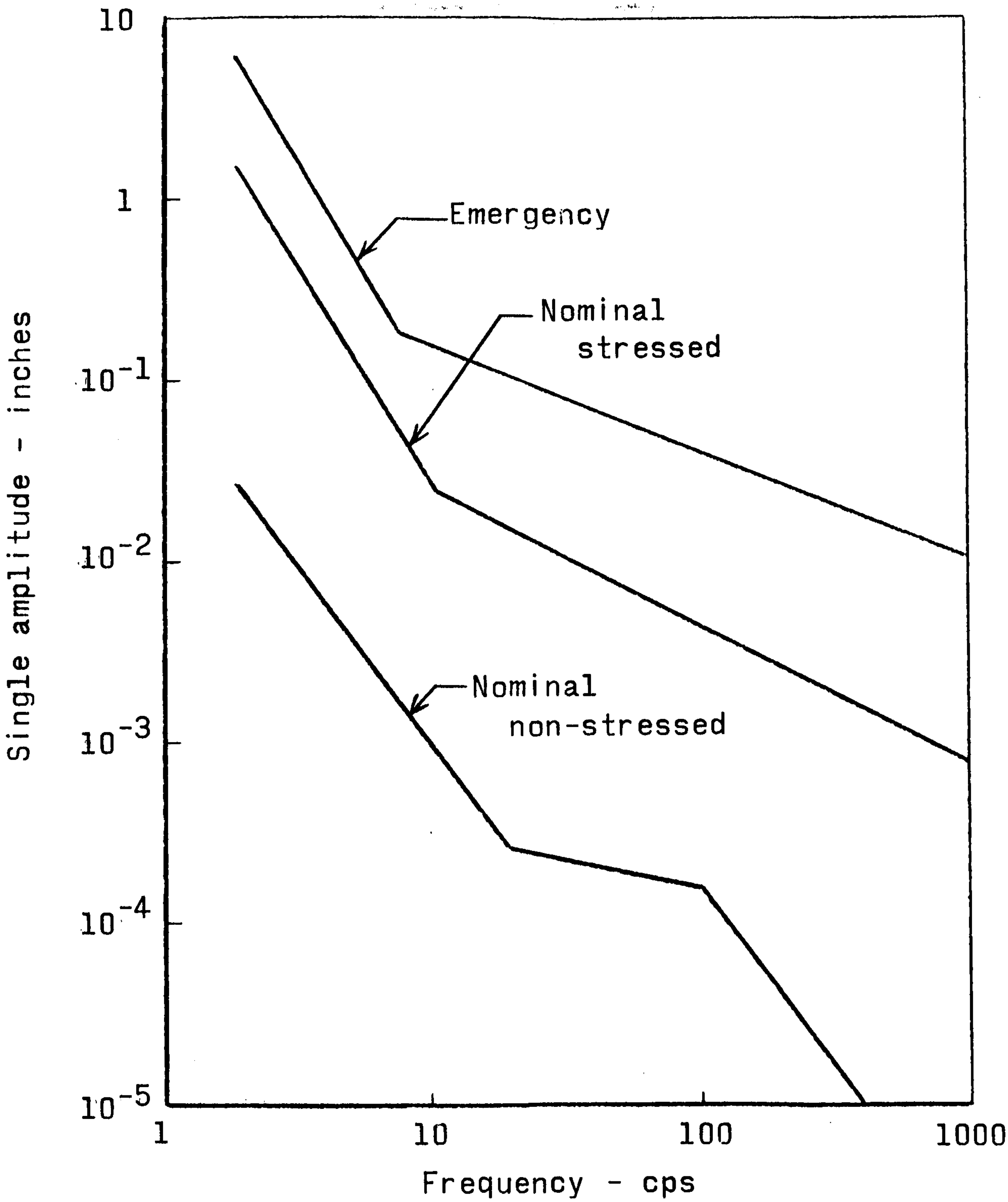

Figure 8.- Vibration limits.

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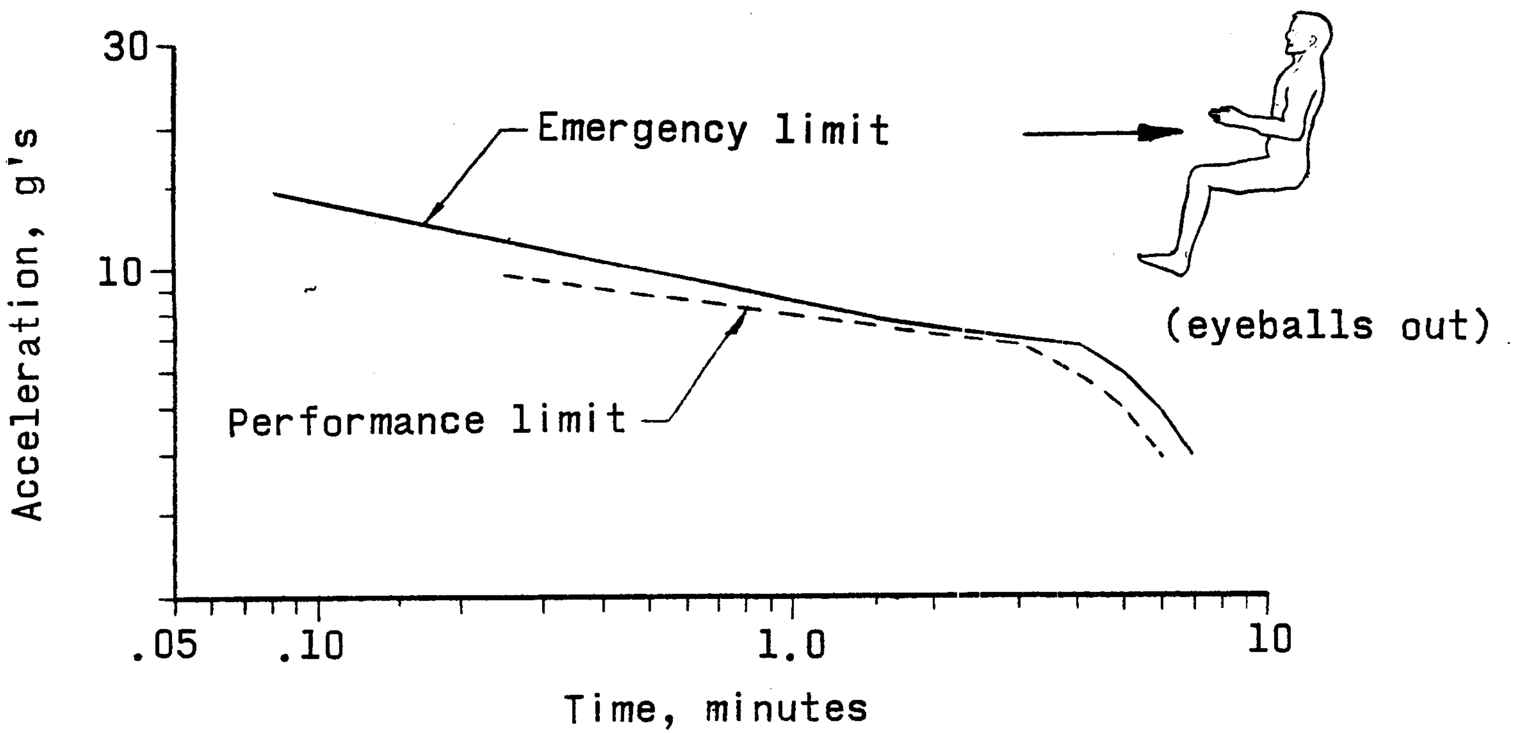

Figure 9. - Sustained acceleration

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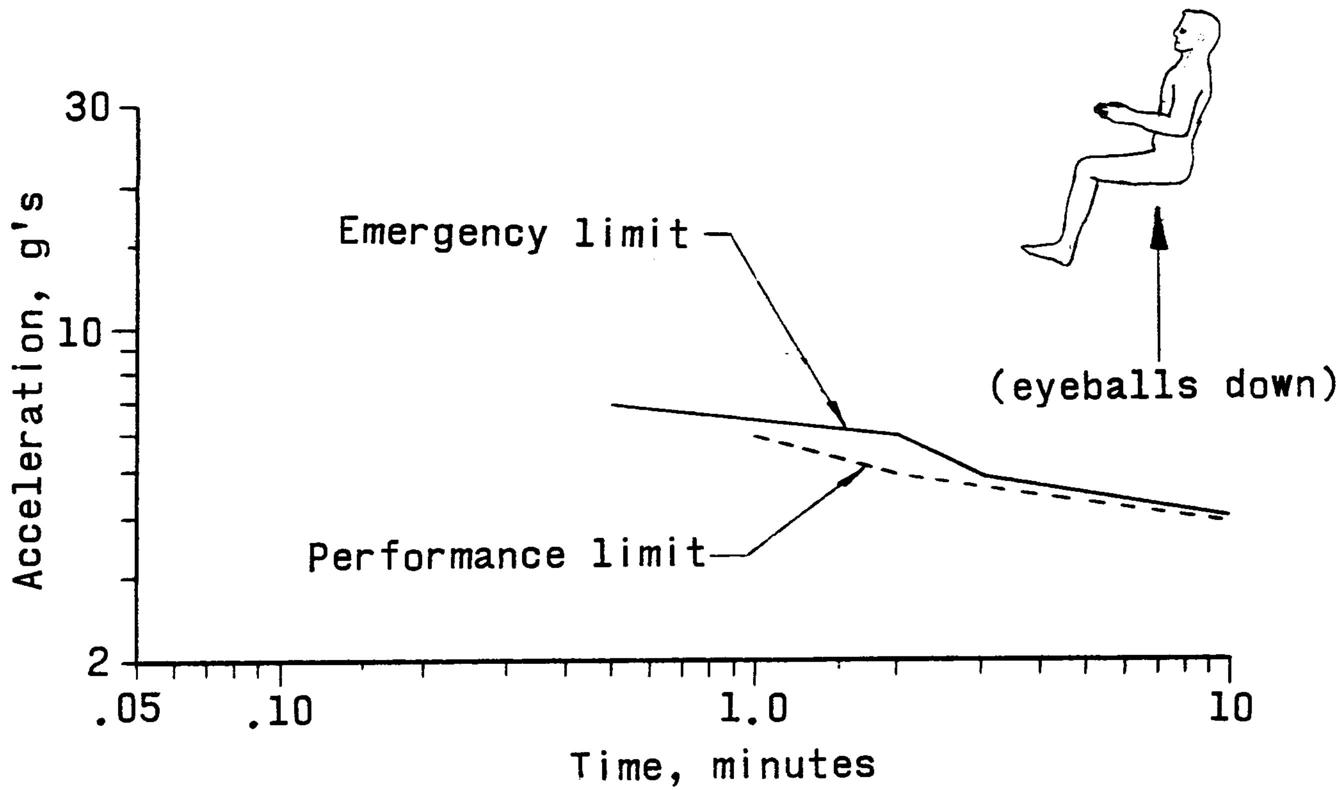

Figure 10 . - Sustained acceleration

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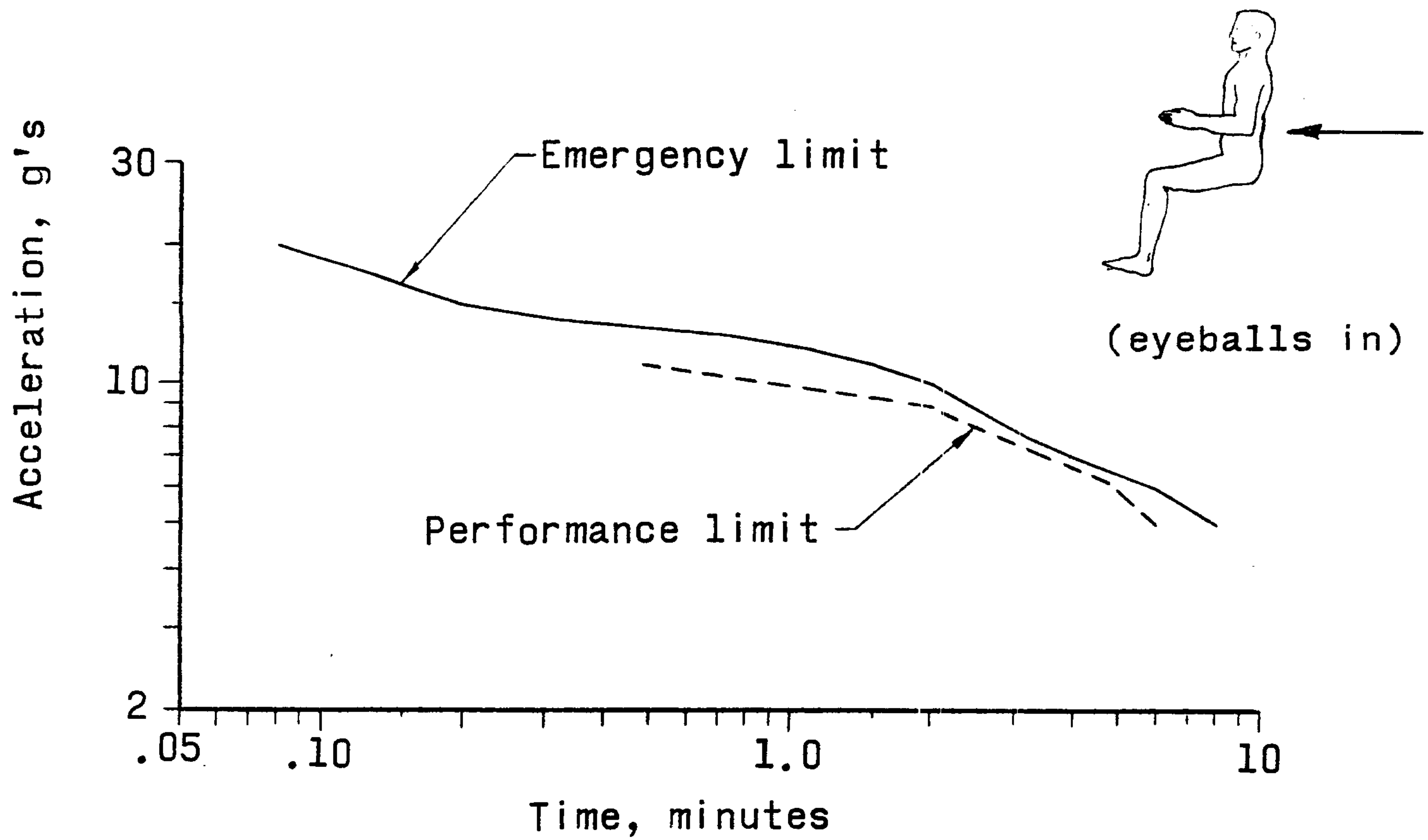

Figure II . - Sustained acceleration

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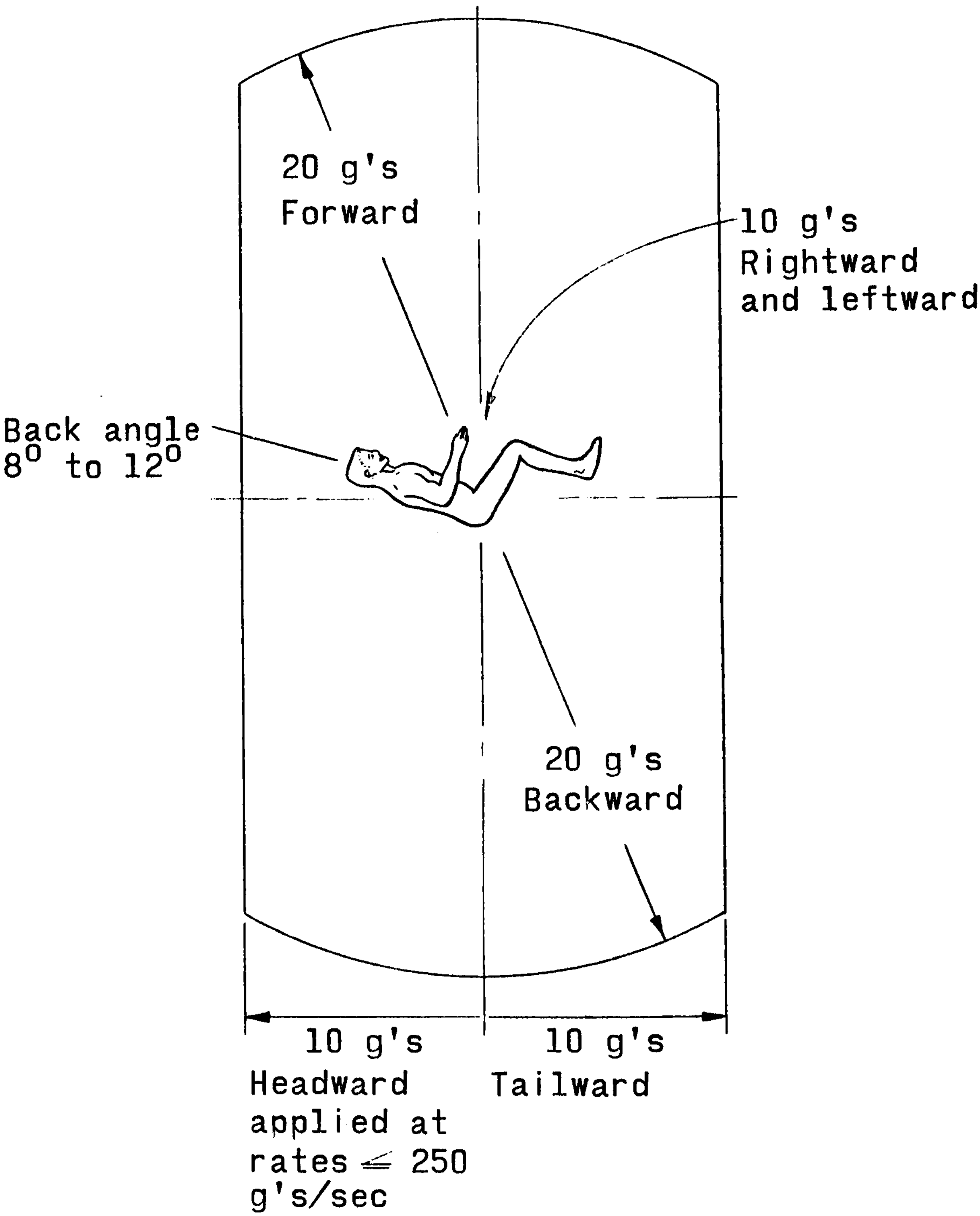

Figure 12.- Impact accelerations - nominal limits.

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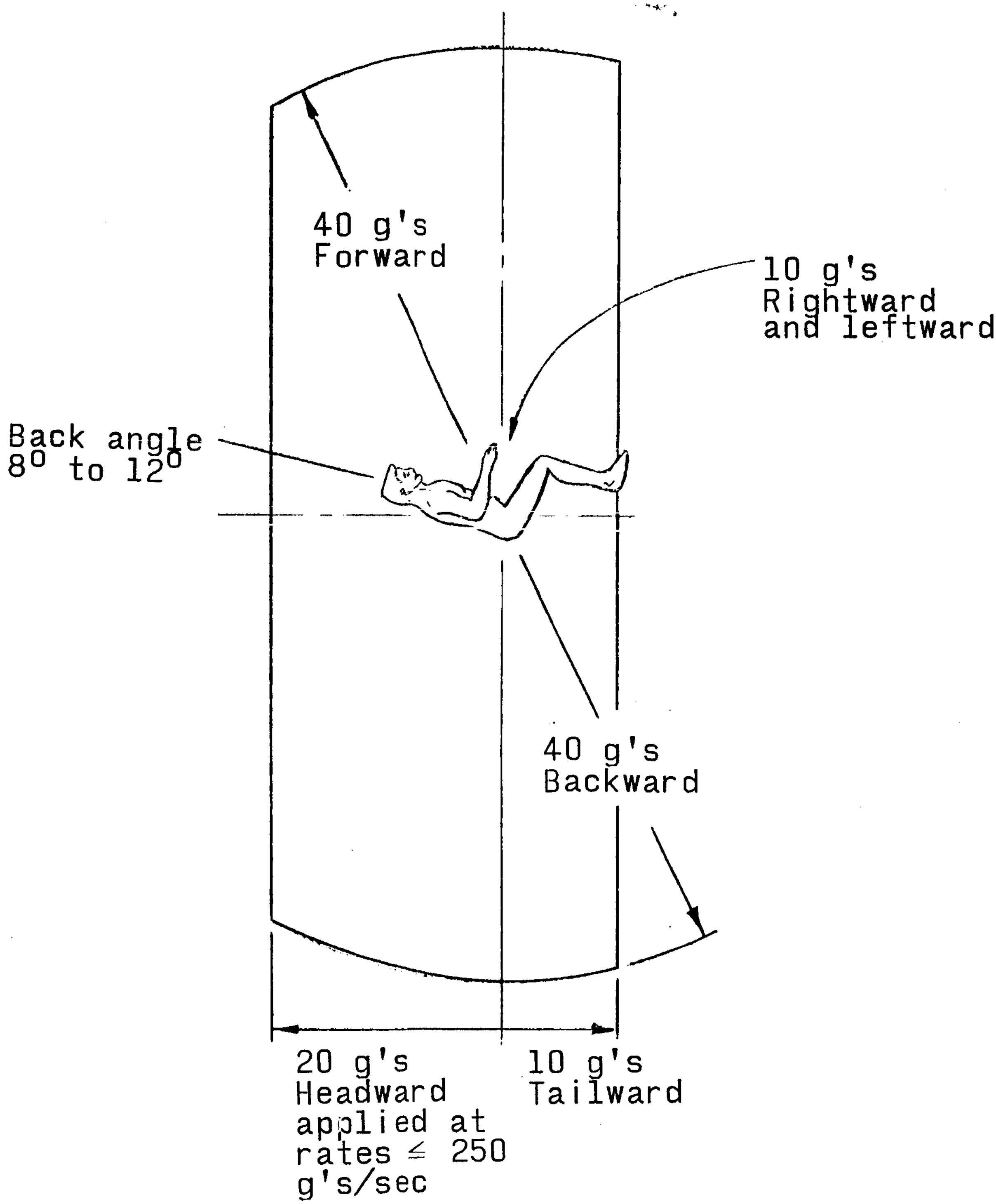

Figure 13.- Impact accelerations - emergency limits.

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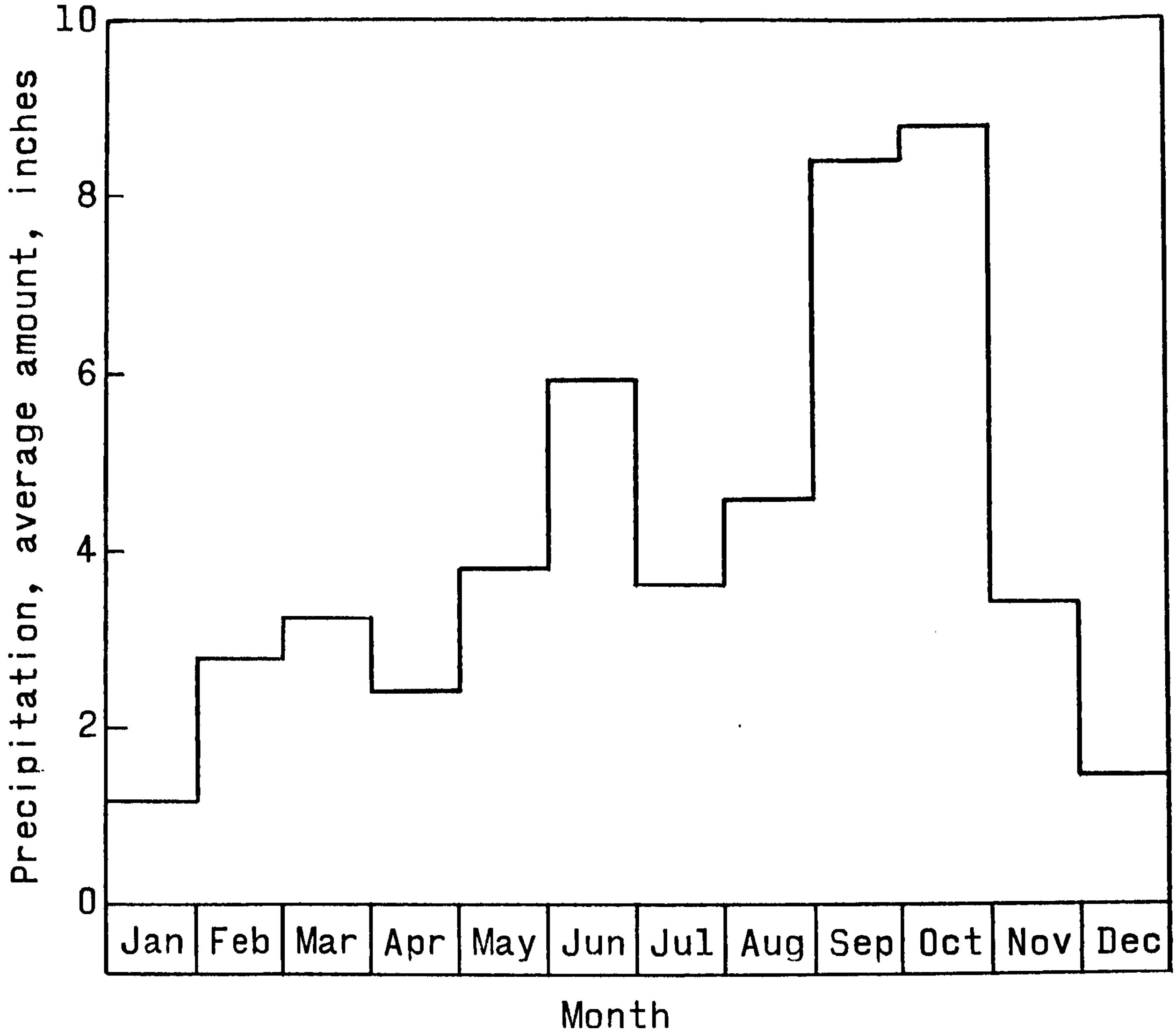

Figure 14.- Average monthly preceiptation, Patrick Air Force Base, Florida.

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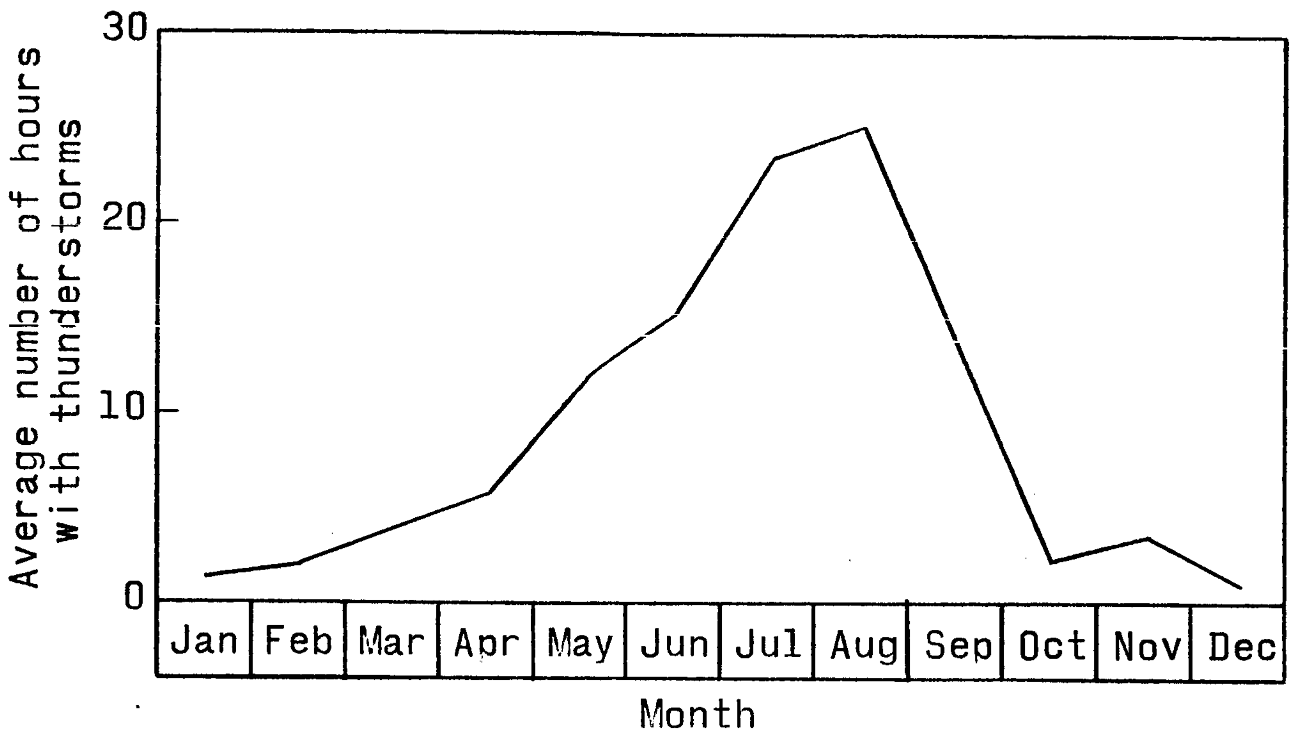

Figure 15.- Average number of hours with thunderstorms, Patrick Air Force Base, Florida.

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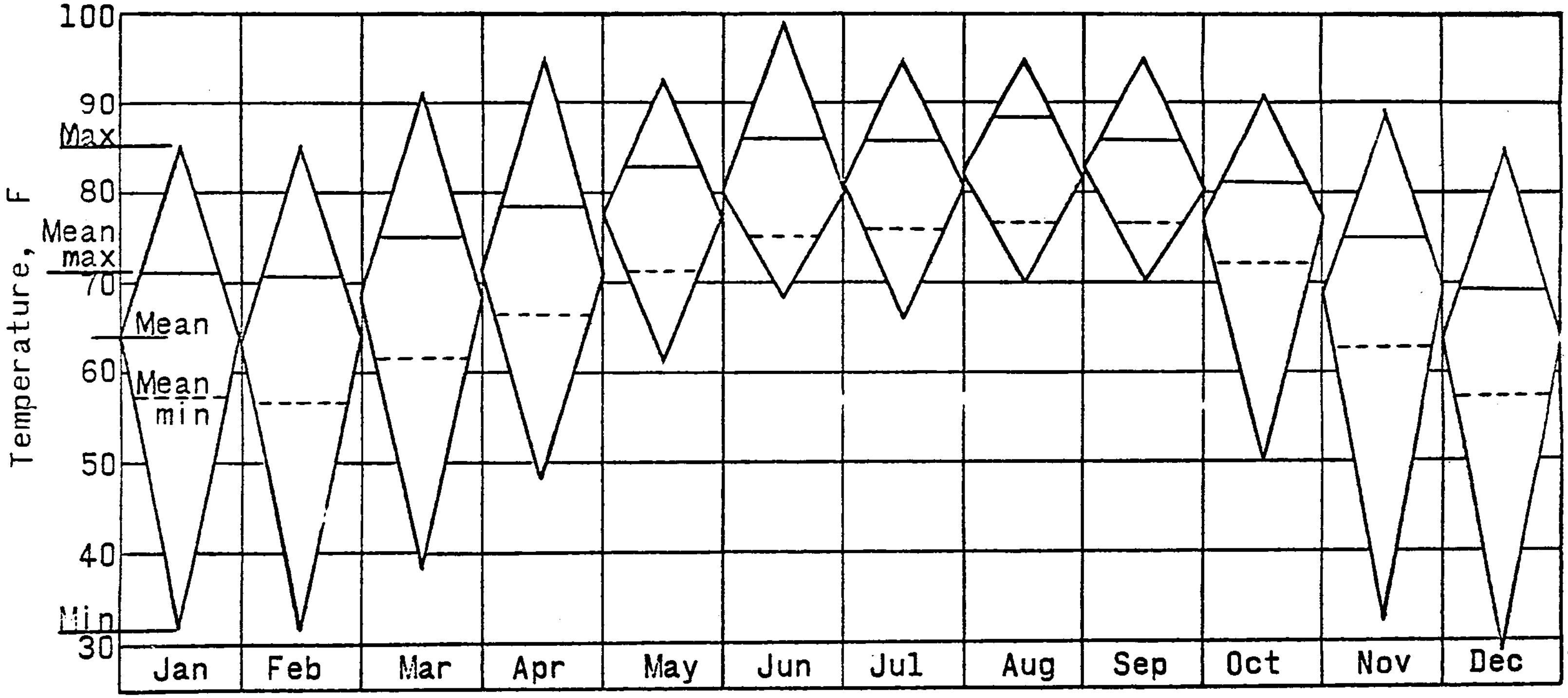

Figure 16.- Monthly temperature variations at Patrick Air Force Base, Florida.

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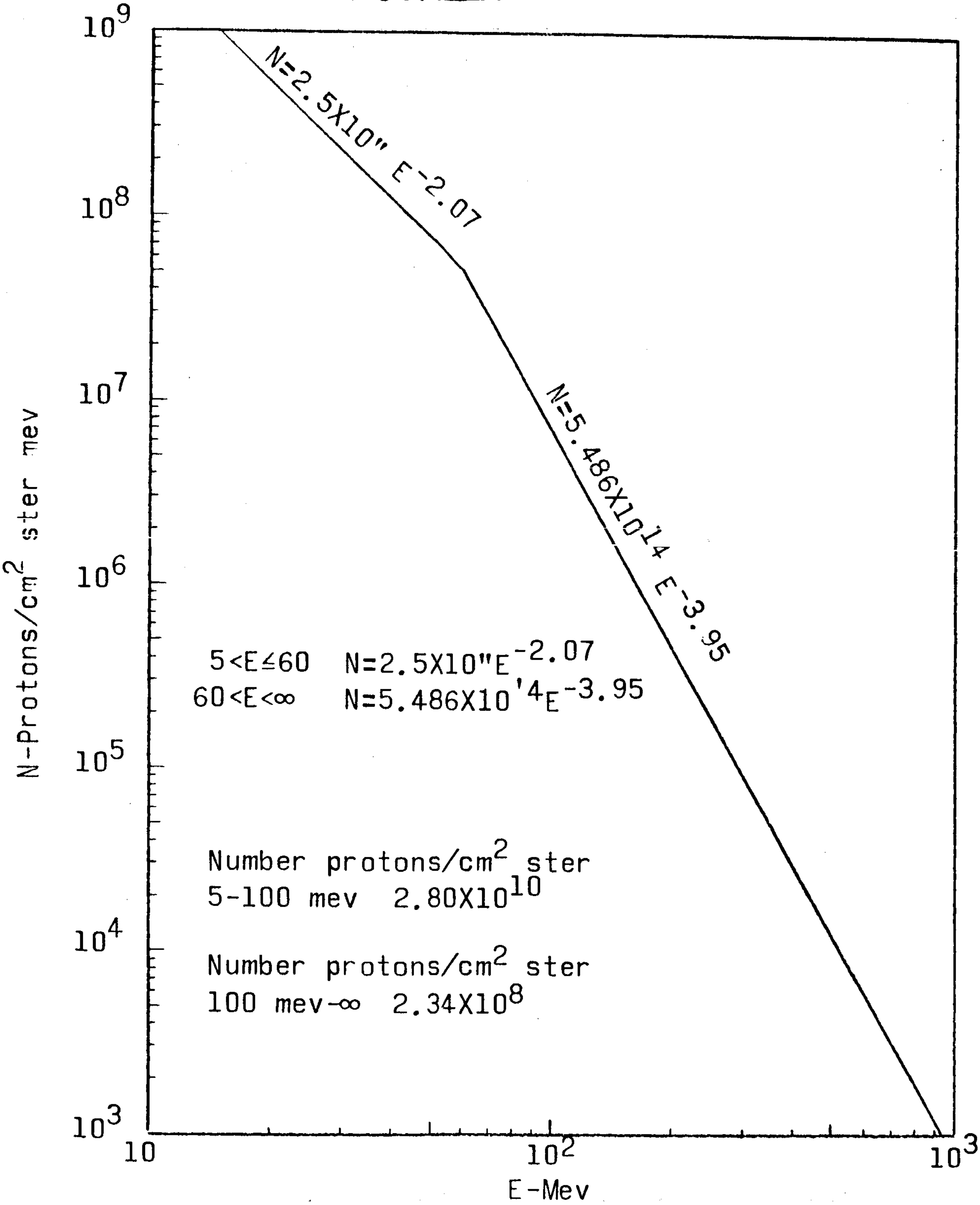

Figure 17.- Time integrated differential energy spectrum for May 10, 1959 event.

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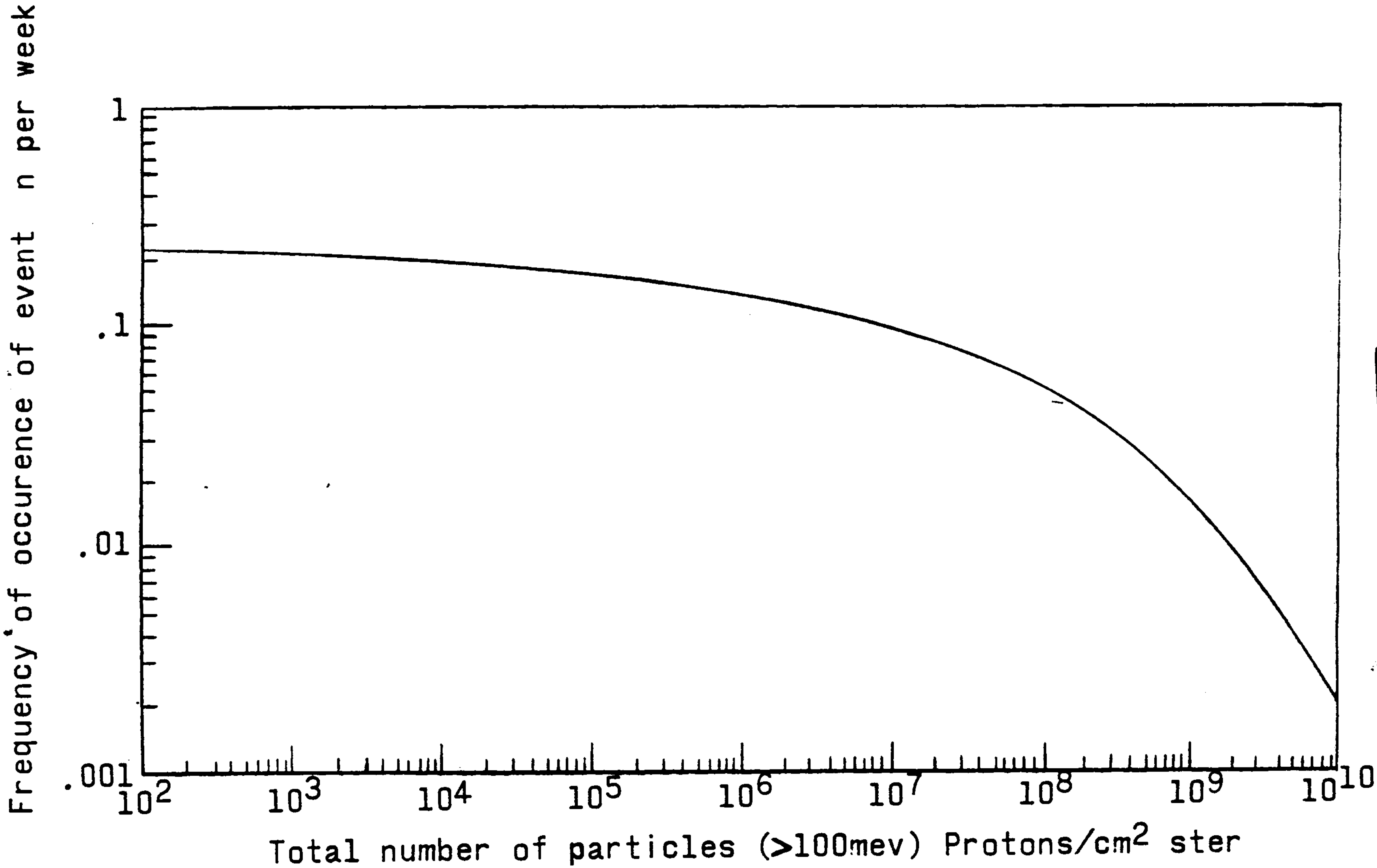

Figure 18.- Frequency distribution of solar proton events.

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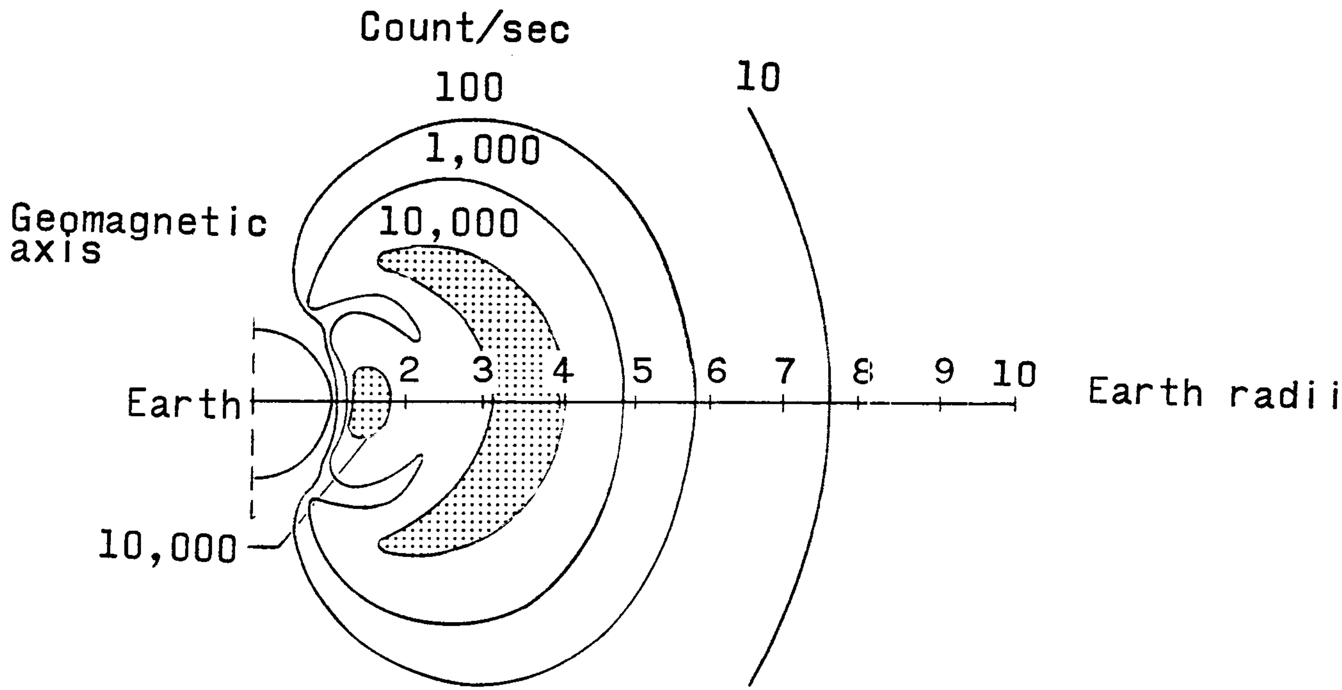

Figure 19.- Model of Van Allen radiation belts.

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Visual magnit.	Mass slugs	Mass grams	Diameter* microns	Diameter* inches	Daily accretion of earth	Velocity KM/sec.	Velocity ft/sec.
0	1.71×10^{-4}	2.5	11,070	.435	3.3×10^{5}	28	91,900
1	6.82×10^{-5}	9.95×10^{-1}	8,160	.320	1.225×10^{6}	28	91,900
2	2.71×10^{-5}	3.96×10^{-1}	6,000	.236	4.55×10^{6}	28	91,900
3	1.08×10^{-5}	1.58×10^{-1}	4,410	.173	1.69×10^{7}	28	91,900
4	4.30×10^{-6}	6.28×10^{-2}	3,250	.127	6.27×10^{7}	28	91,900
5	1.71×10^{-6}	2.50×10^{-2}	2,390	9.36×10^{-2}	2.33×10^{8}	28	91,900
6	6.82×10^{-7}	9.95×10^{-3}	1,760	6.91×10^{-2}	5.84×10^{8}	28	91,900
7	2.71×10^{-7}	3.96×10^{-3}	1,290	5.07×10^{-2}	1.47×10^{9}	28	91,900
8	1.08×10^{-7}	1.58×10^{-3}	951	3.74×10^{-2}	3.69×10^{9}	27	88,600
9	4.30×10^{-8}	6.28×10^{-4}	700	3.75×10^{-2}	9.26×10^{9}	26	85,300
10	1.71×10^{-8}	2.50×10^{-4}	514	2.02×10^{-2}	2.33×10^{10}	25	82,000
11	6.82×10^{-9}	9.95×10^{-5}	379	1.49×10^{-2}	5.84×10^{10}	24	78,700
12	2.71×10^{-9}	3.96×10^{-5}	279	1.09×10^{-2}	1.47×10^{11}	23	75,500
13	1.08×10^{-9}	1.58×10^{-5}	205	8.04×10^{-3}	3.69×10^{11}	22	72,200
14	4.30×10^{-10}	6.28×10^{-6}	151	5.93×10^{-3}	9.26×10^{11}	21	68,900
15	1.71×10^{-10}	2.50×10^{-6}	111	4.35×10^{-3}	2.33×10^{12}	20	65,600
16	6.28×10^{-11}	9.95×10^{-7}	81.6	3.20×10^{-3}	5.84×10^{12}	19	62,300
17	2.71×10^{-11}	3.96×10^{-7}	60	2.36×10^{-3}	1.47×10^{13}	18	59,100
18	1.08×10^{-11}	1.58×10^{-7}	44.1	1.73×10^{-3}	3.69×10^{13}	17	55,800
19	4.30×10^{-12}	6.28×10^{-8}	32.5	1.27×10^{-3}	9.26×10^{13}	16	52,500
20	1.71×10^{-12}	2.50×10^{-8}	23.9	9.36×10^{-4}	2.33×10^{14}	15	49,200
21	6.82×10^{-13}	9.95×10^{-9}	17.6	6.91×10^{-4}	5.84×10^{14}	15	49,200
22	2.71×10^{-13}	3.96×10^{-9}	12.9	5.07×10^{-4}	1.47×10^{15}	15	49,200
23	1.08×10^{-13}	1.58×10^{-9}	9.5	3.74×10^{-4}	3.69×10^{15}	15	49,200
24	4.30×10^{-14}	6.28×10^{-10}	7.00	2.75×10^{-4}	9.26×10^{15}	15	49,200
25	1.71×10^{-14}	2.50×10^{-10}	5.14	2.02×10^{-4}	2.33×10^{16}	15	49,200

Figure 20. -Whipple's distribution for sporadic meteroroids

*Diameters based on ρ_m=3.5 grams/cc.

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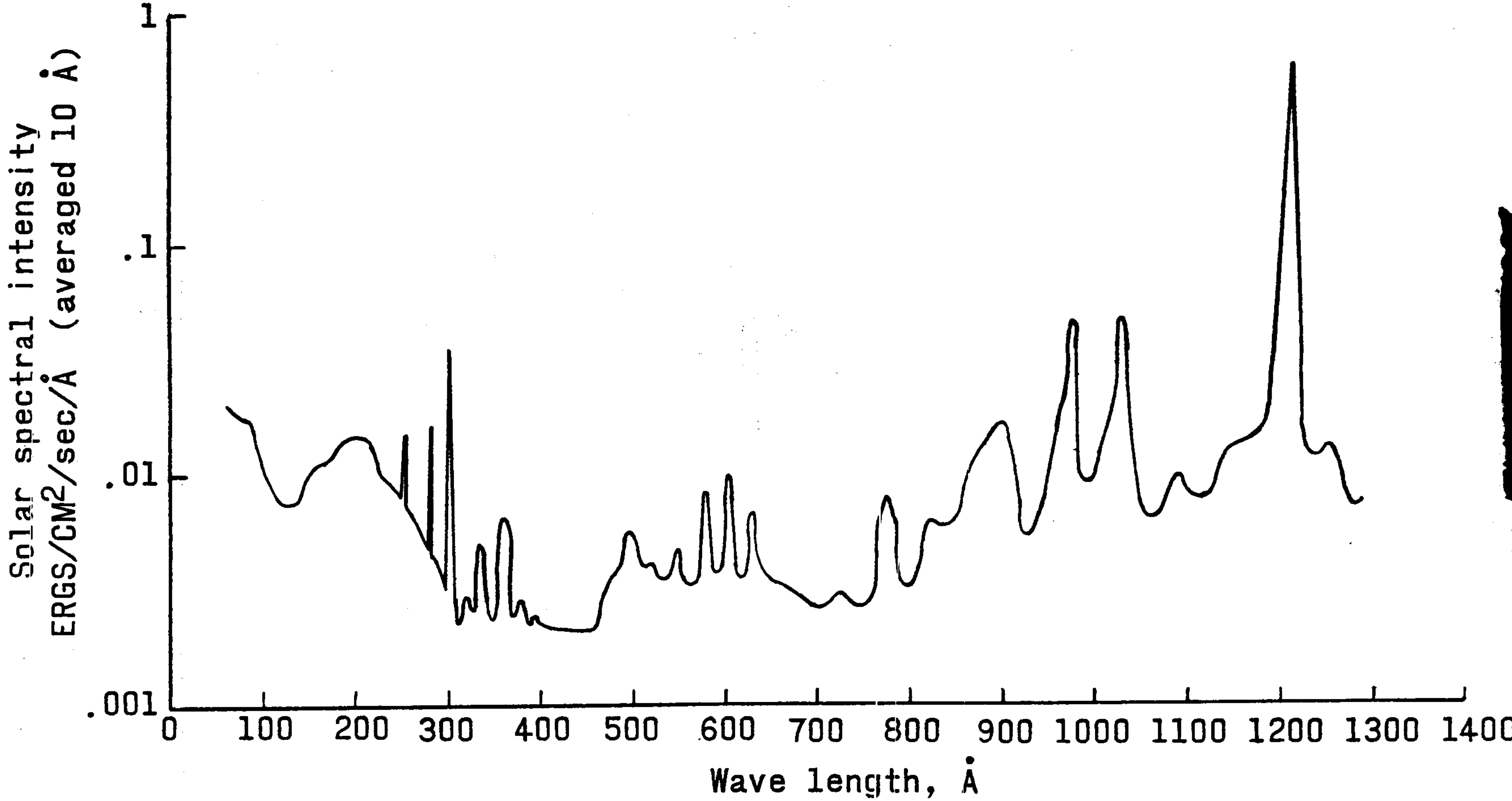

Figure 21.- Electromagnetic spectrum for solar radiation.

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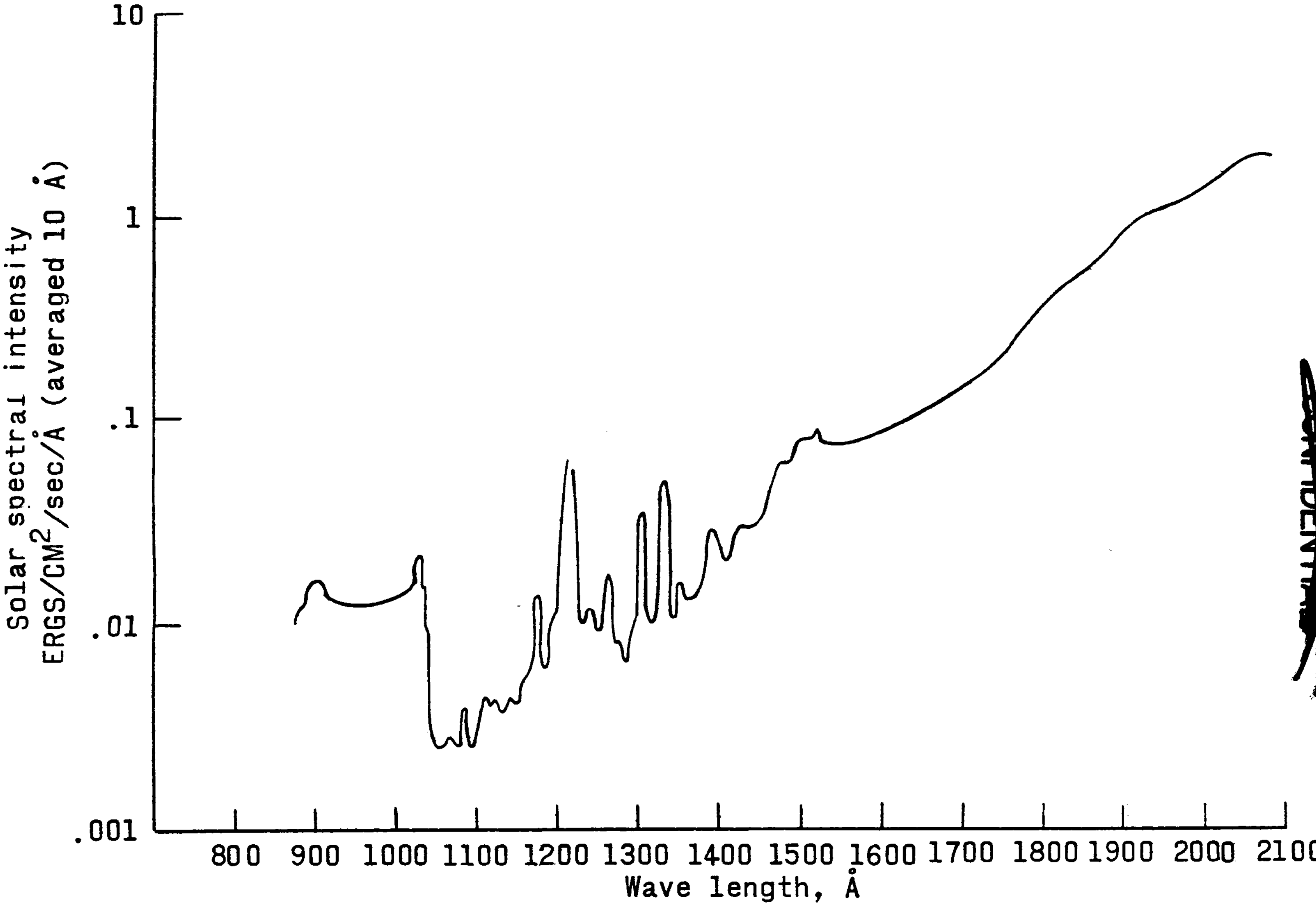

Figure 22.- Electromagnetic spectrum for solar radiation.

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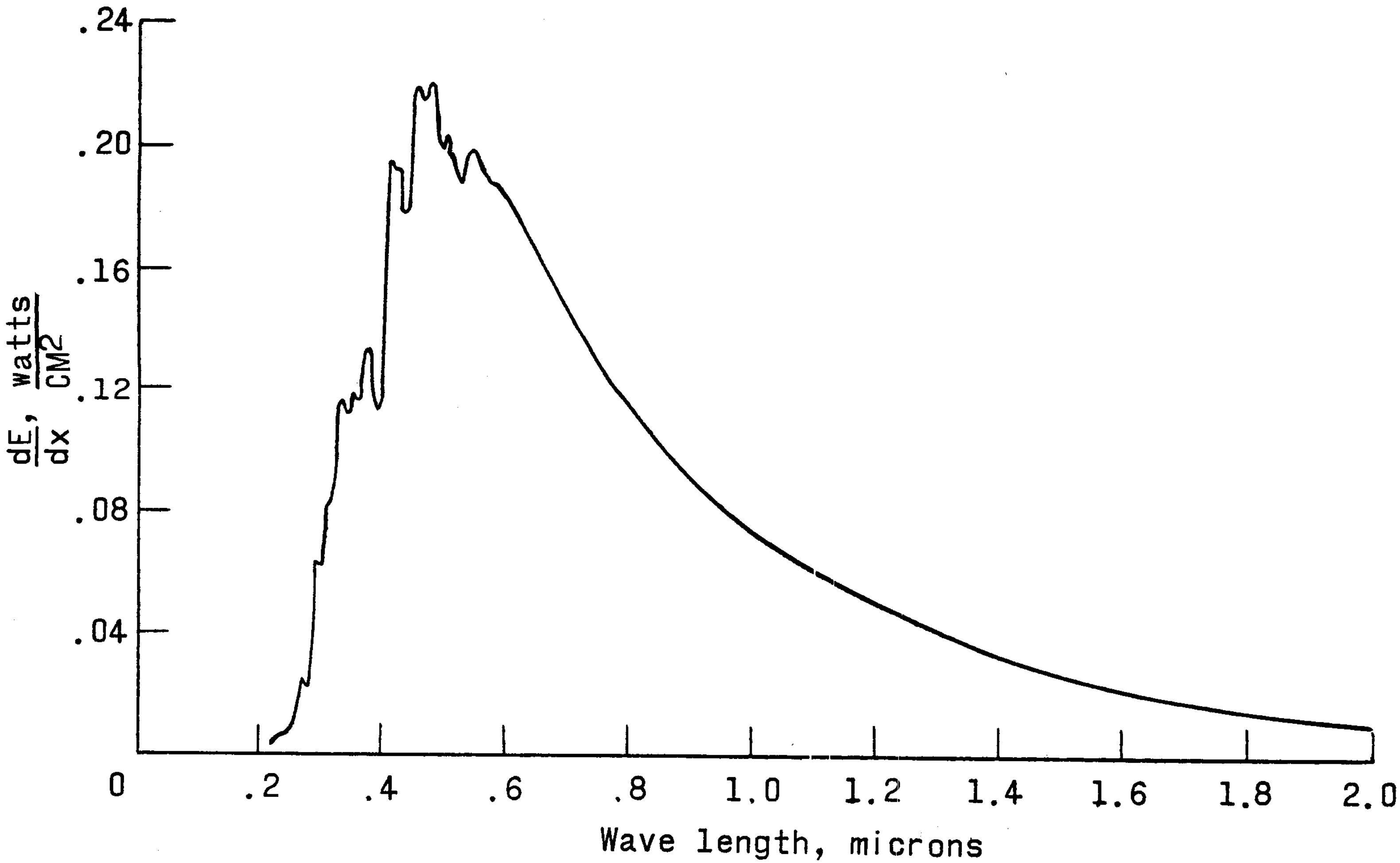

Figure 23.- Electromagnetic spectrum for solar radiation.

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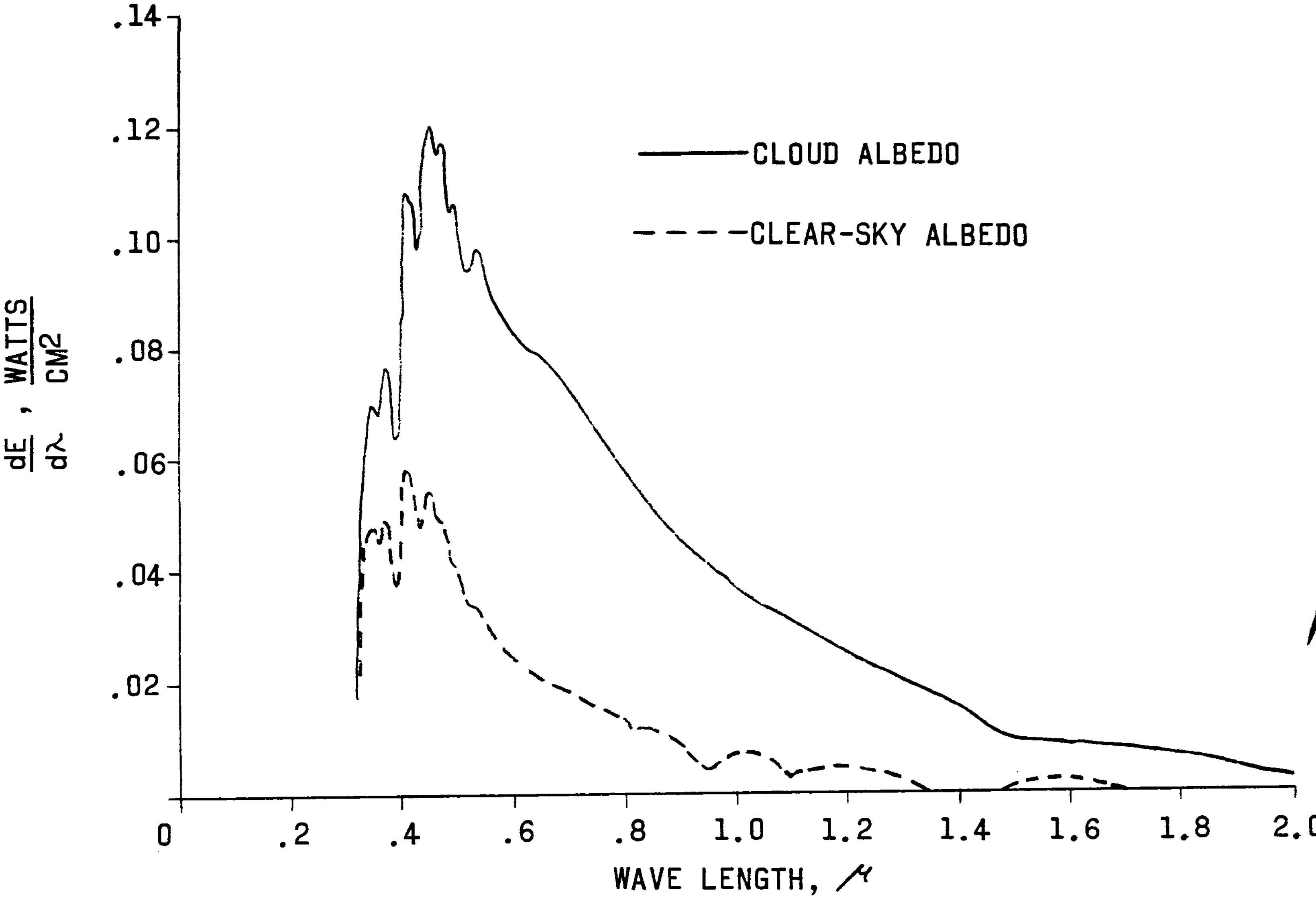

Figure 24.- Spectrum of the Earth's albedo.

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Equivalent pressure	Equivalent density	Composition
10^{-6} dynes/cm^2	10^{-16} grams/cm^3	Hydrogen atoms

Figure 25. - Interplanetary atmosphere.

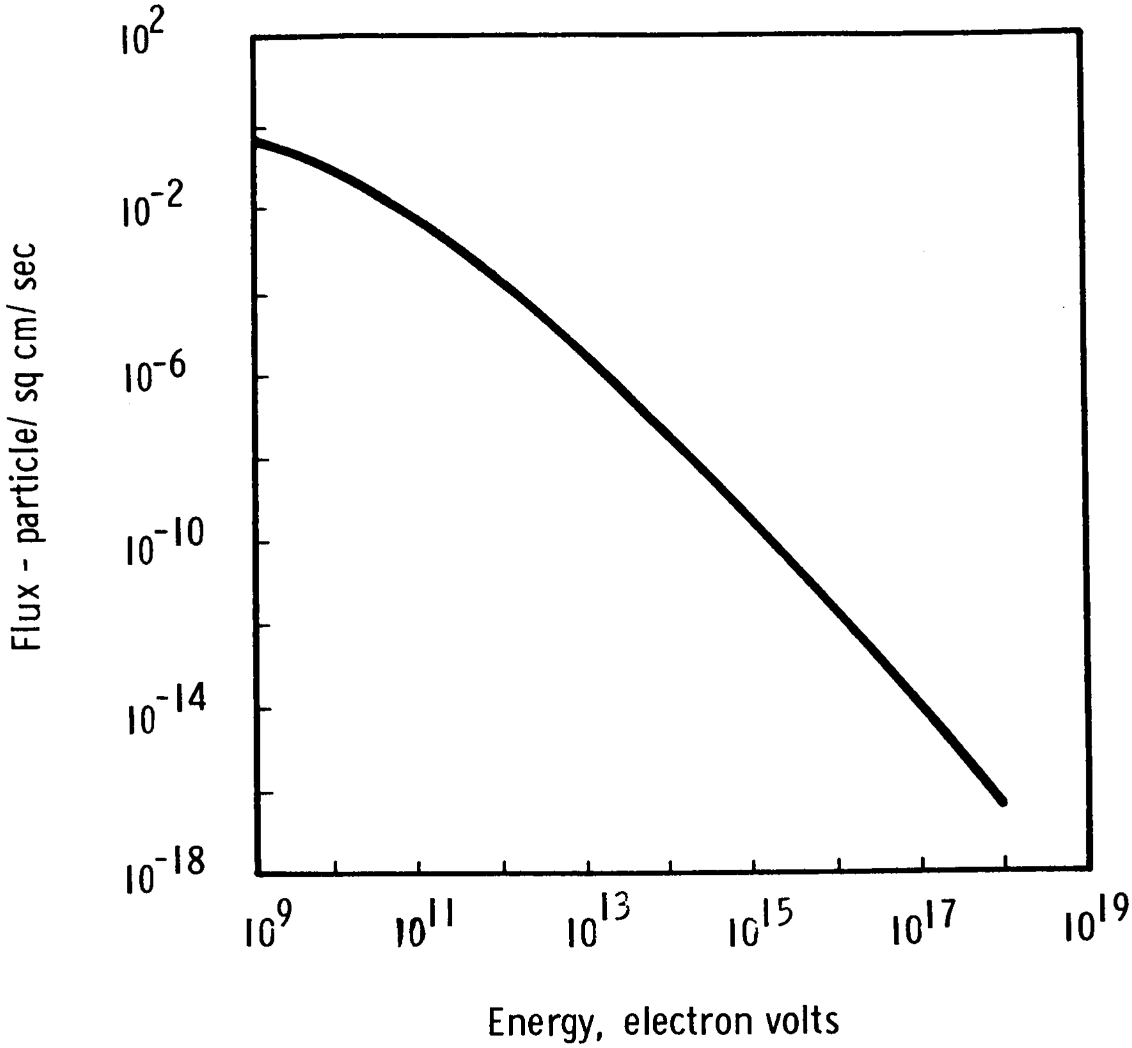

Figure 26. - Galactic cosmic ray flux

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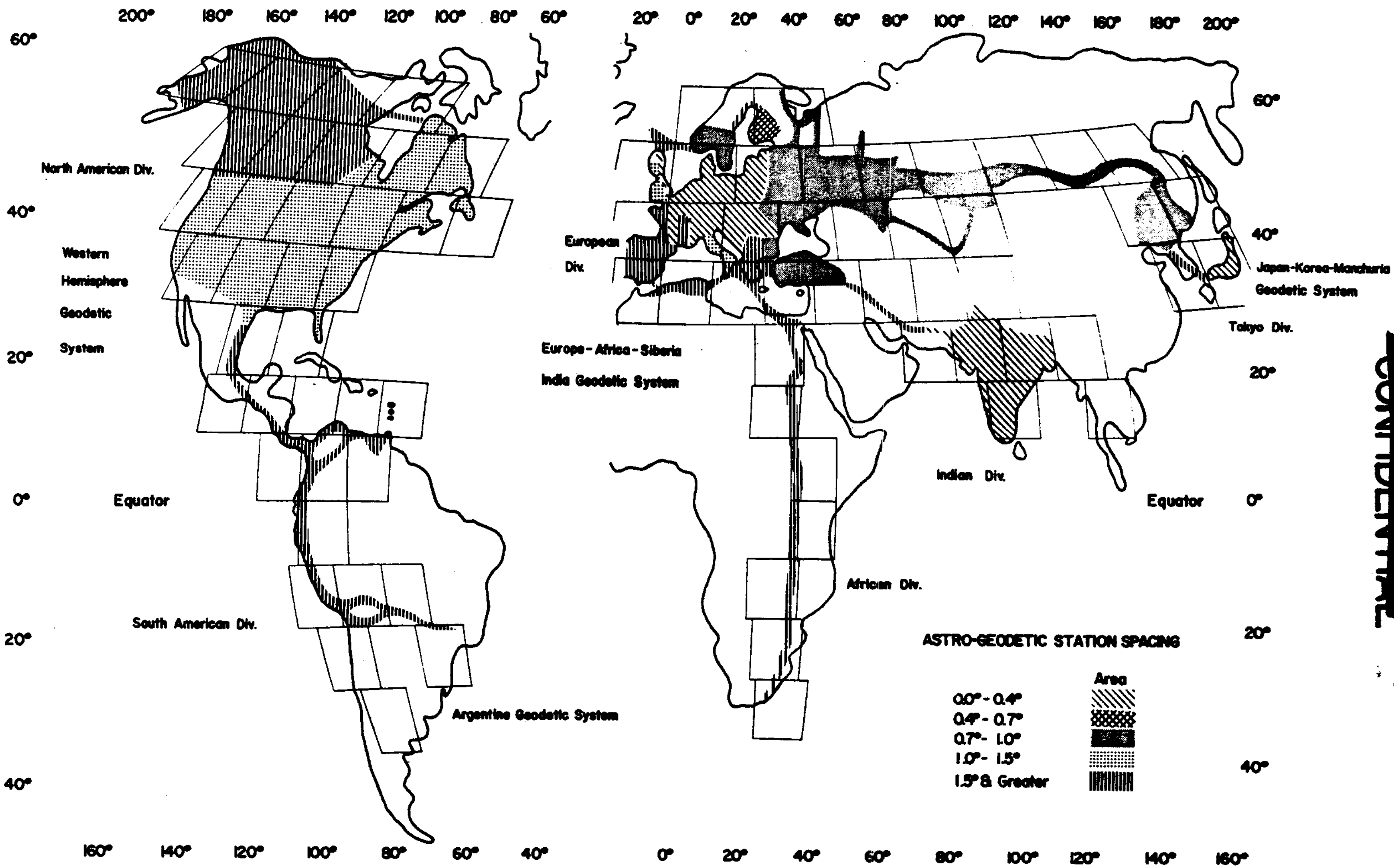

Figure 27- Astro-geodetic geoid data station spacing and distribution.

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Systems	Stations	Correction Δu Meters	Δv Meters	Δw Meters
Western Hemisphere Geodetic System	NAD	−23	+142	+196
	SAD	−303	+98	−315
	SAO SP59	+4	+299	+15
	Vangard	−12	+235	+120
	σ	±26	±22	±22
Europe-Africa-Siberia-India Geodetic System	ED	−57	−37	−96
	Indian	+200	+782	+271
	Arc	−109	−70	−289
	SAO SP59	−150	−2	−33
	σ	±23	±29	±23
Japan-Korea-Manchuria Geodetic System	Tokyo	−89	+551	+710
	SAO SP59	−29	−209	−147
	σ	±40	±53	±40
Australia Geodetic System	Sidney	+198	+262	−21
	SAO SP59	+149	−83	+116
	σ (Estimated)	±75	±90	±35
Argentina Geodetic System	SAO SP59	−81	+131	+105
	σ (Estimated)	±180	±160	±160

Figure 28. - Geodetic station location correction data. (Reference 13).

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Planet	M_s / M_p	ω	f	GM
Sun	1.	3.0050435×10^{-6}	0	$1.32715445 \times 10^{11}$
Mercury	6, 120, 000.		0	
Venus	406, 645.	Synchronous	0	3.247695×10^{5}
Earth	332, 488.		1/298. 30	3.986032×10^{5}
Mars	3, 088, 000.	7.0882232×10^{-5}	1/191. 8	4.297780×10^{4}
Jupiter	1, 047. 39	1.7734082×10^{-4}	1/15. 2	1.267106×10^{8}
Saturn	3, 500.	1.7055335×10^{-4}	1/10. 2	
Uranus	22, 869.	1.6135556×10^{-4}	1/14	
Neptune	18, 889.	1.1140400×10^{-4}	1/58. 5	
Pluto	400, 000.			

$$G = (6.668 \pm .0005) \times 10^{-8} \ \frac{cm^3}{sec^2 \ gram}$$

$$M_e = (5.977 \pm .004) \times 10^{27} \ \text{grams}$$

$$T = 86164.09054 \ \text{seconds}$$

$$A_u = 1.49599 \times 10^{11} \ \text{meters}$$

$$\frac{M_e}{M_m} = 81.375$$

Figure 29. - Sun, moon, and planetary constants.

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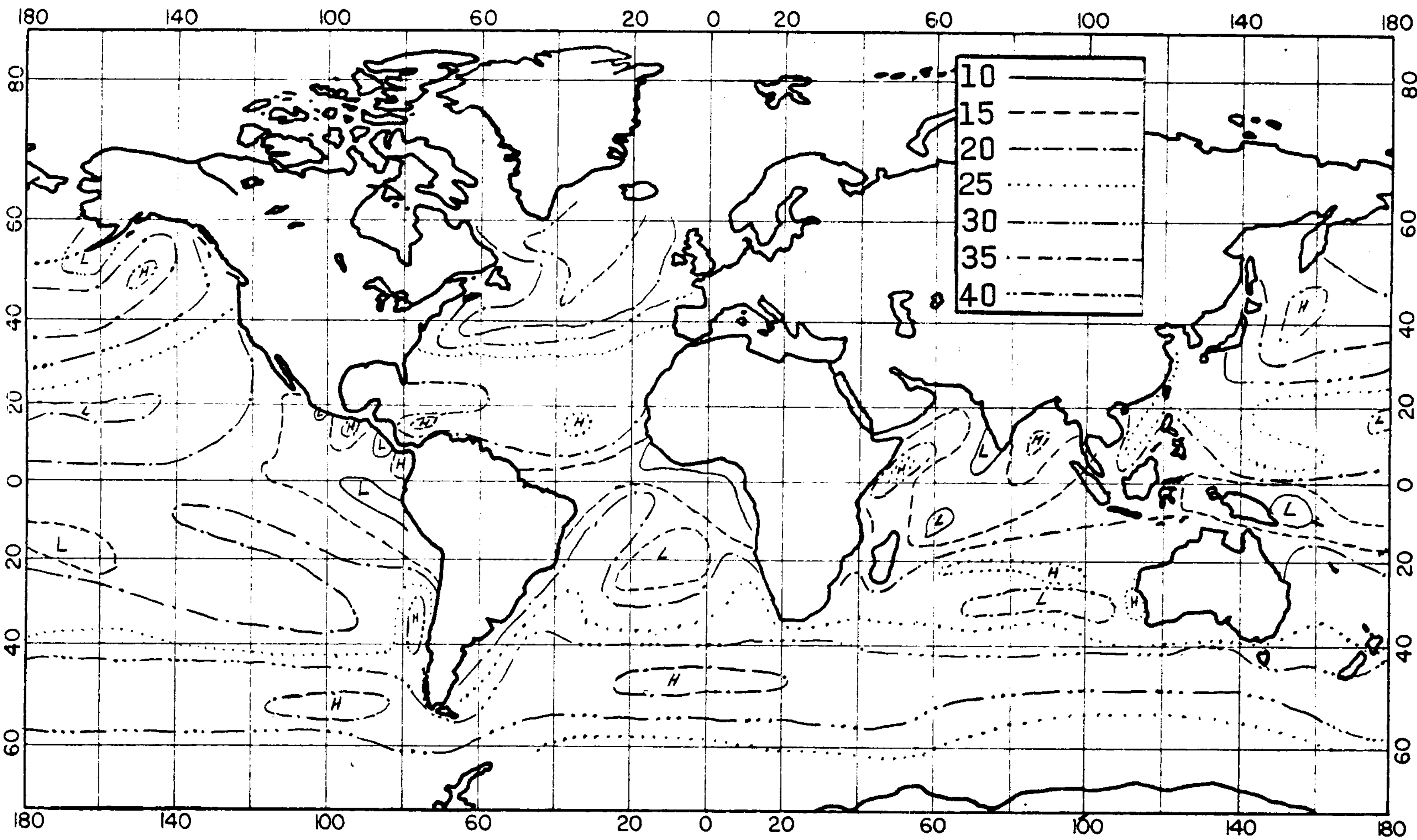

(a) January.

Figure 30.- Wind speed (knots) exceeded 10 percent of the time.

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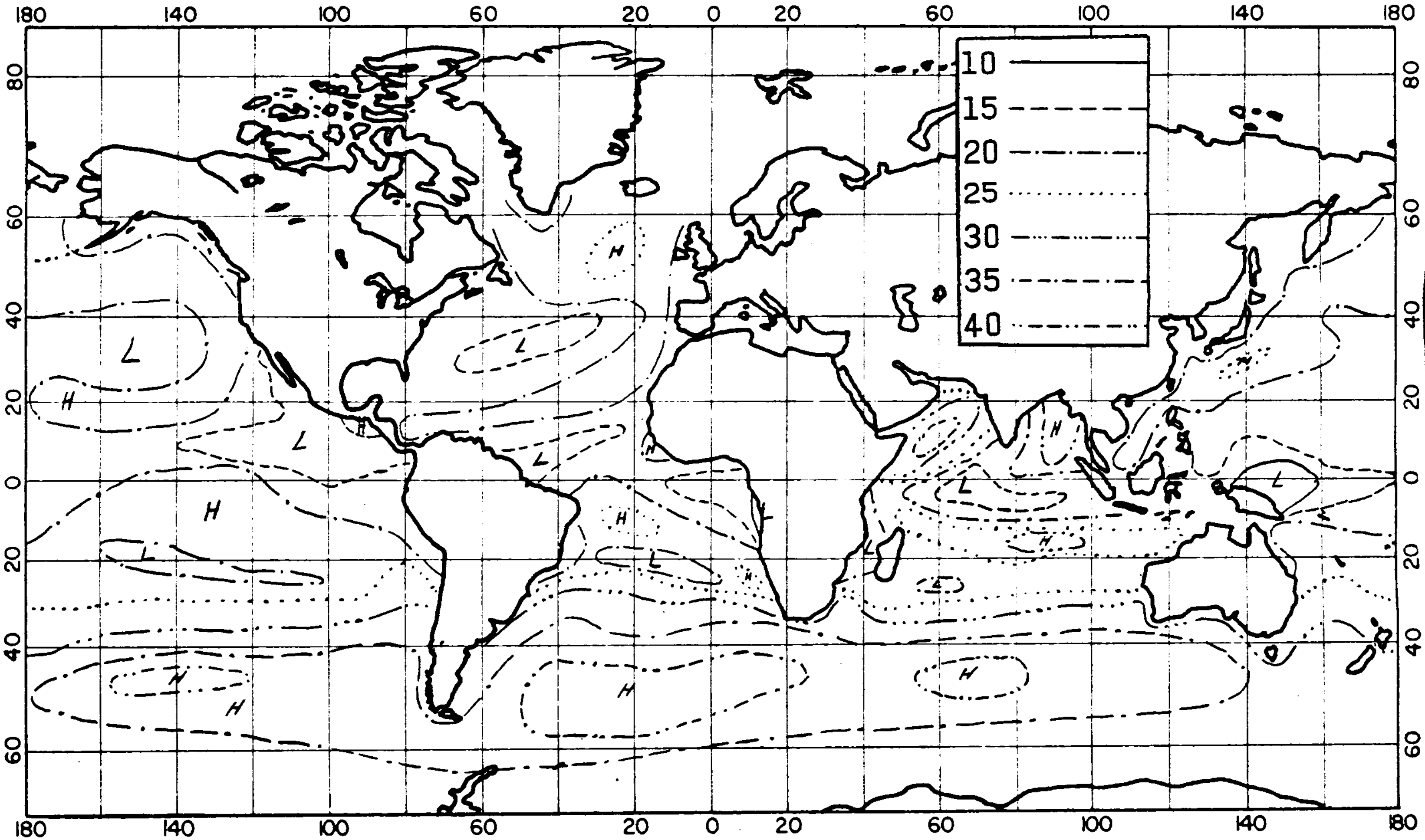

(b) July.

Figure 30.- Concluded.

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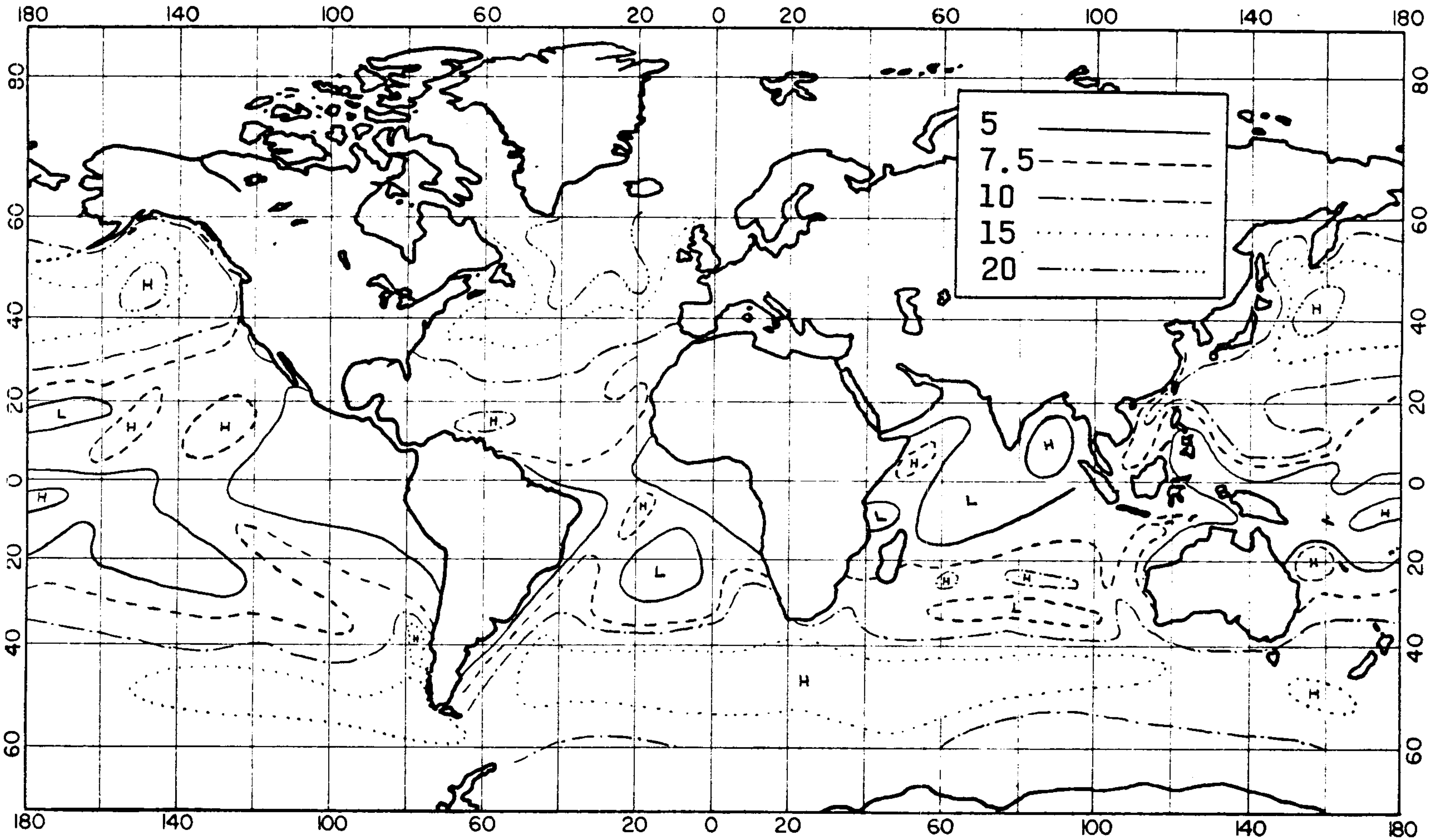
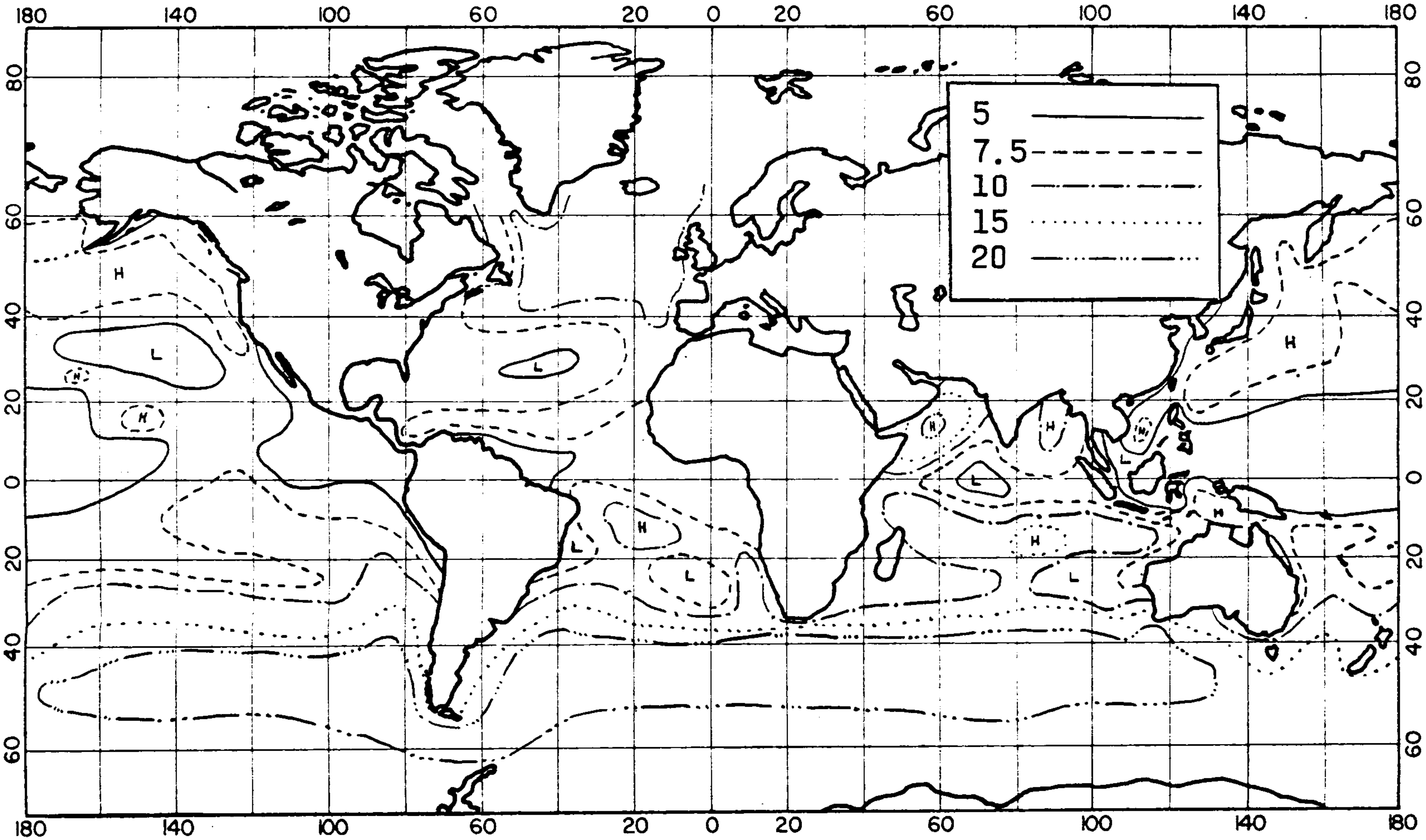


(a) January.

Figure 31 .- Wave height (feet) exceeded 10 percent of the time.

[redacted]



(b) July.

Figure 31 .- Concluded.

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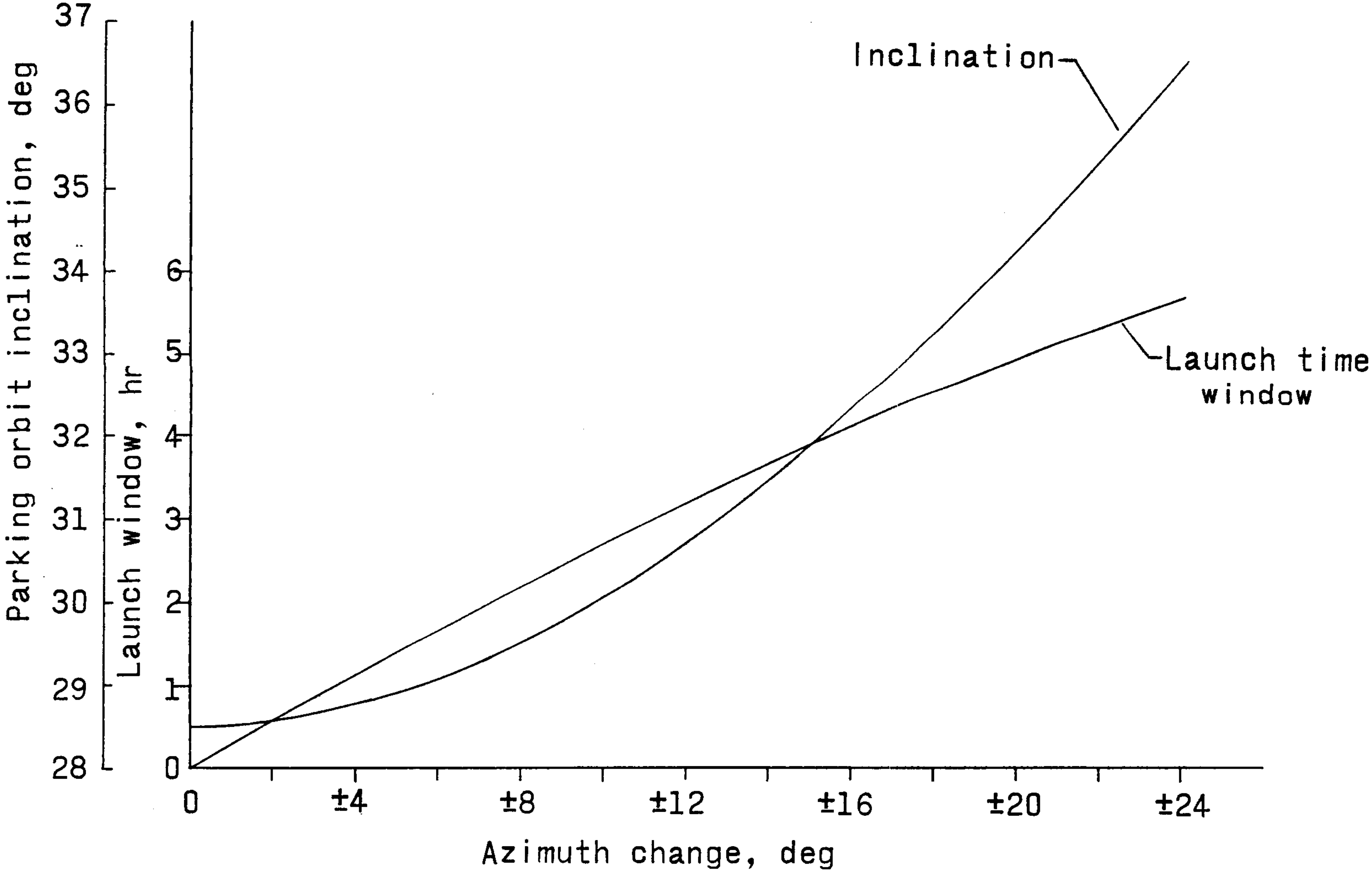

Figure 32.- Launch time window for variation in the translunar trajectory.

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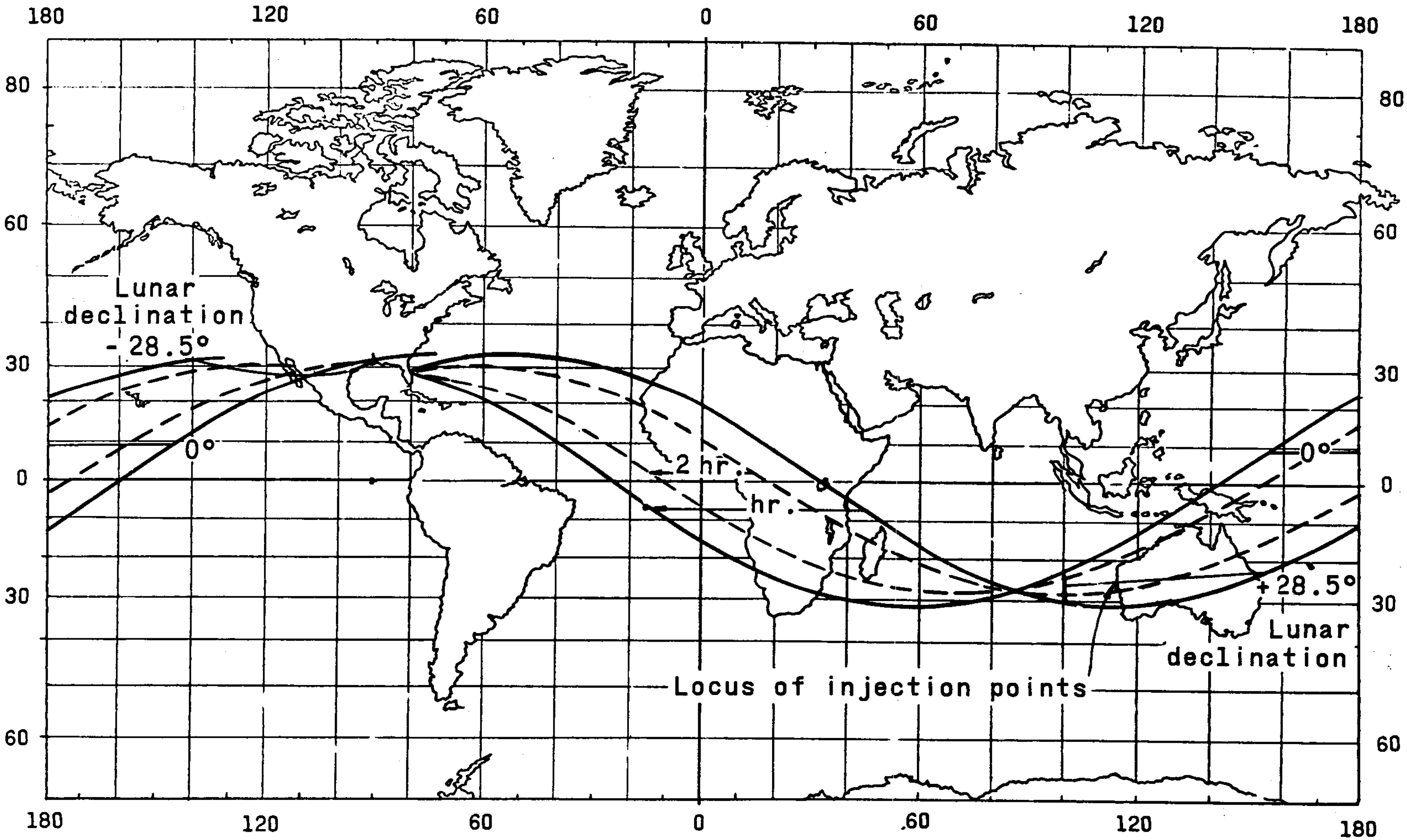

Figure 33- Parking orbit boundaries for launch time window.

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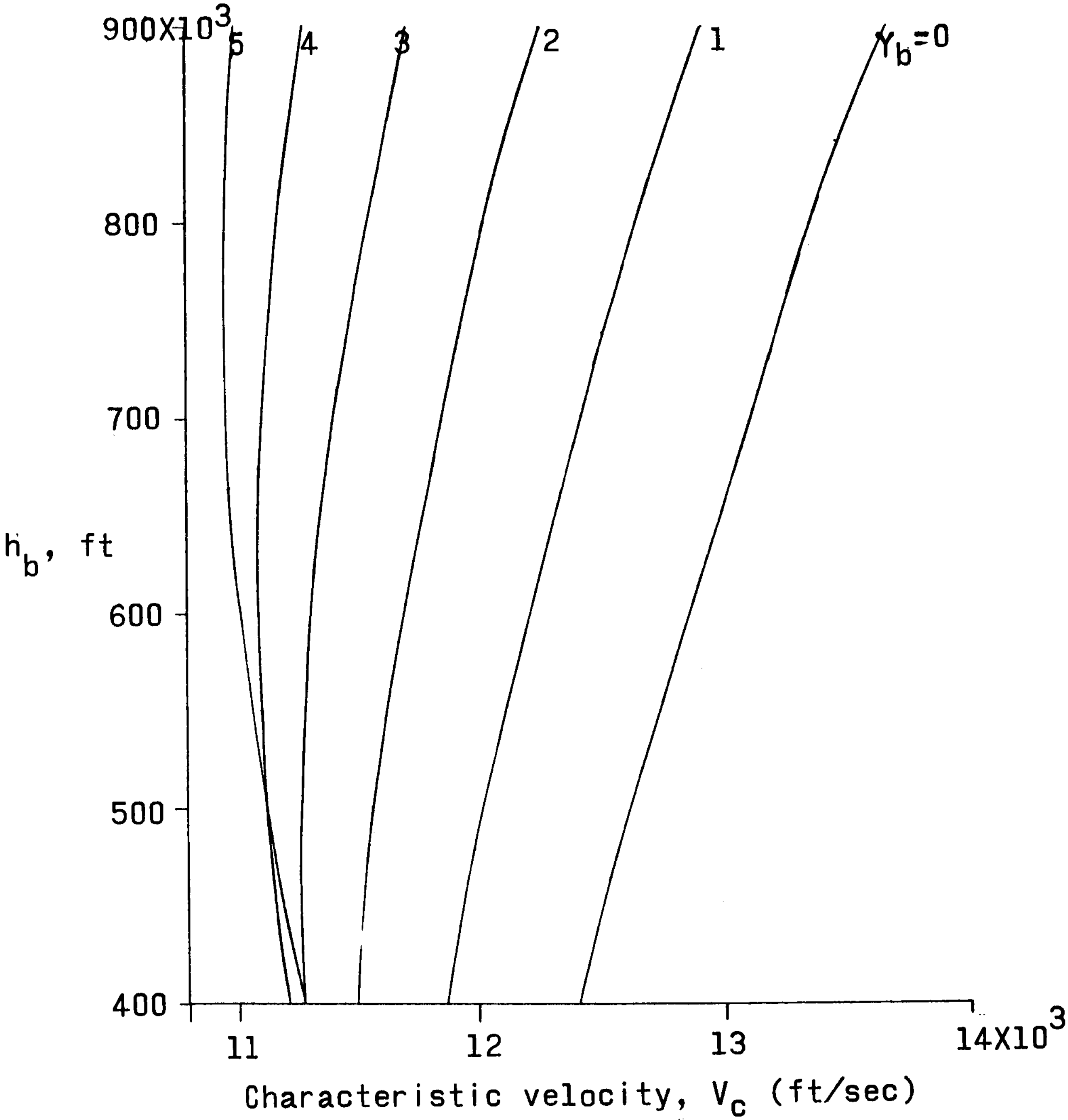

(a) T/W = 0.5, I_{sp} = 420

Figure 34.- Optimum booster performance to escape from a 600,000 ft parking orbit.

[redacted]

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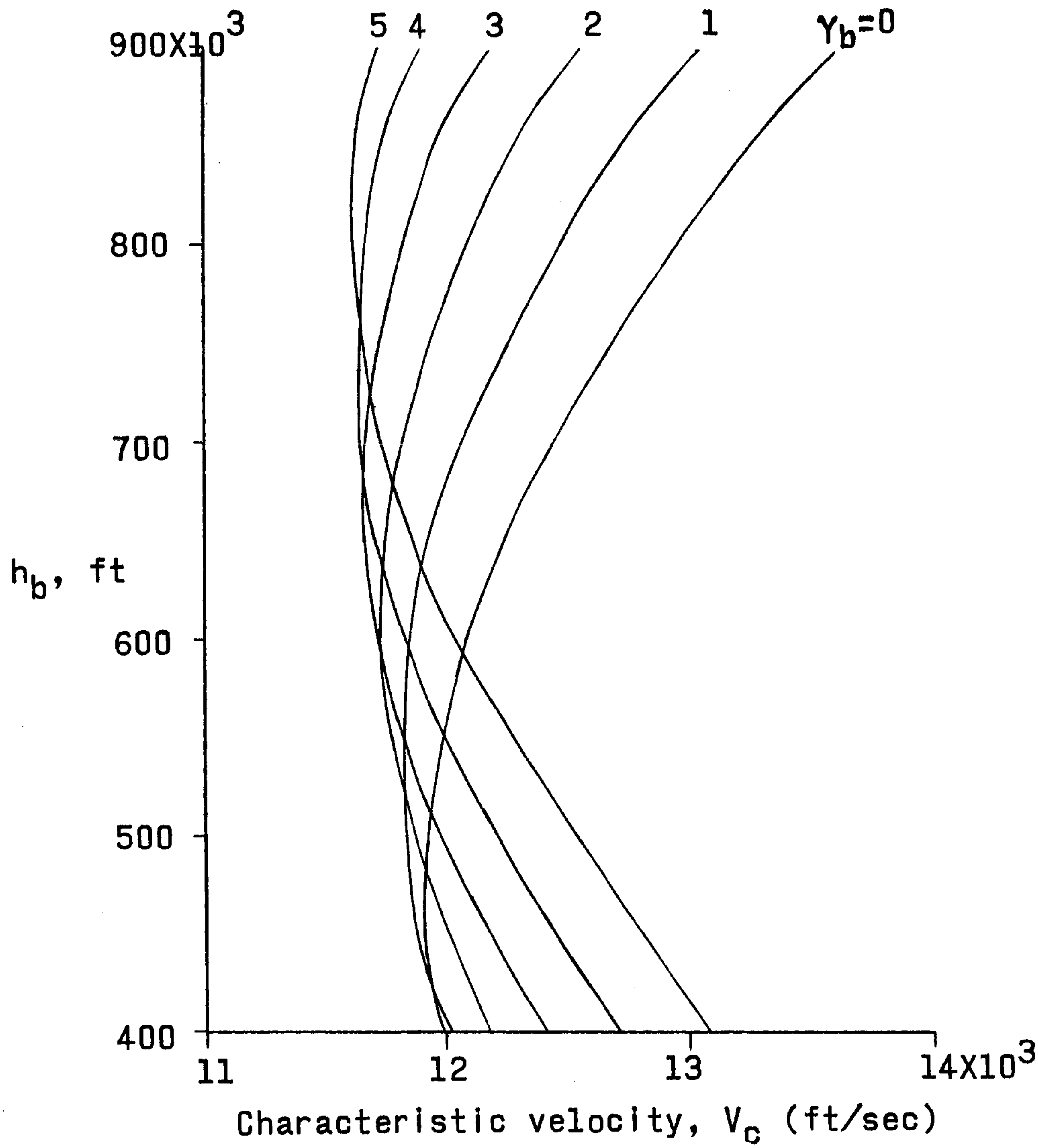

(b) $T/W = 1.0$, $I_{sp} = 420$

Figure 34.- Continued.

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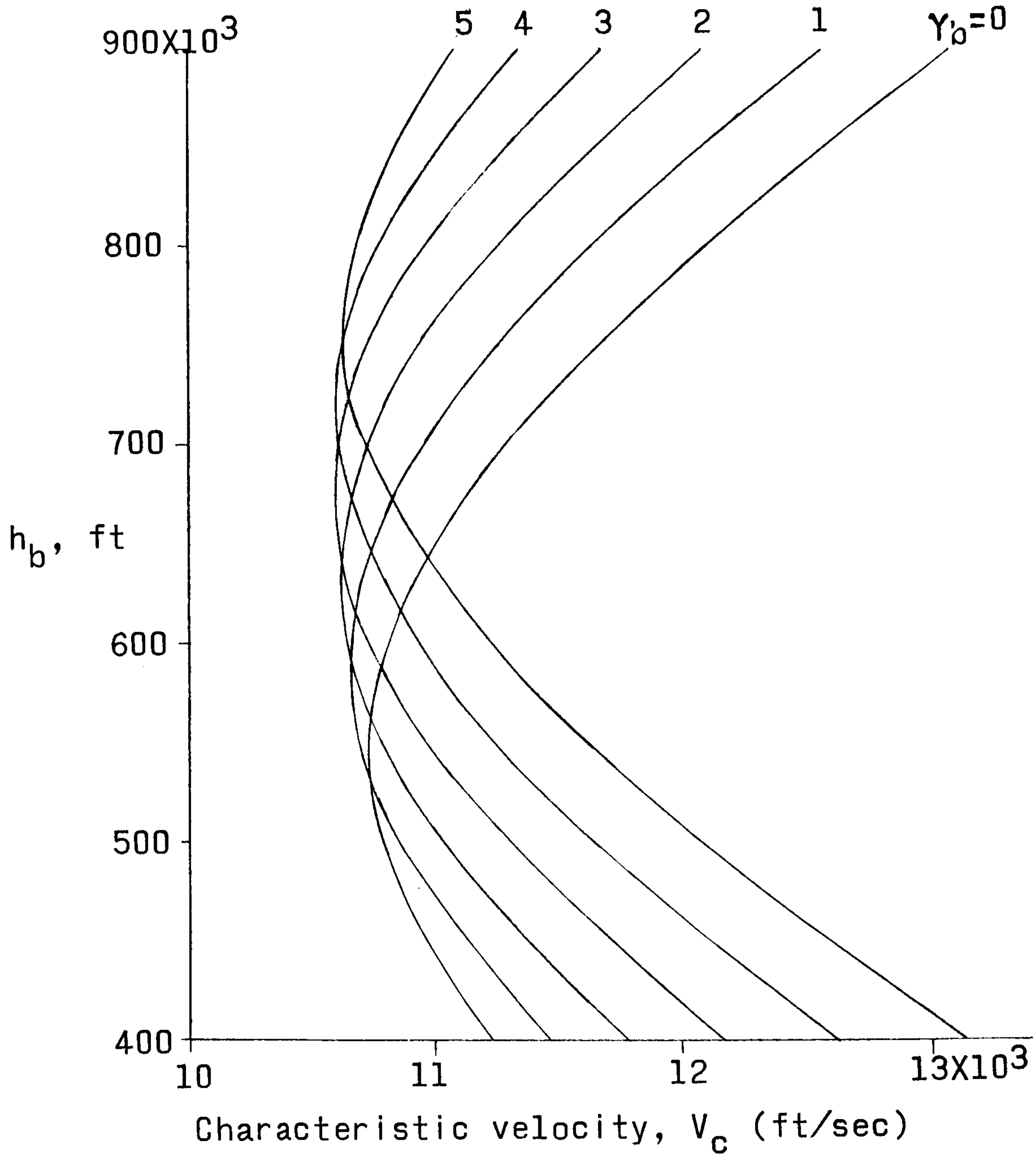

(c) T/W = 1.50, I_{sp} = 420

Figure 34.- Concluded.

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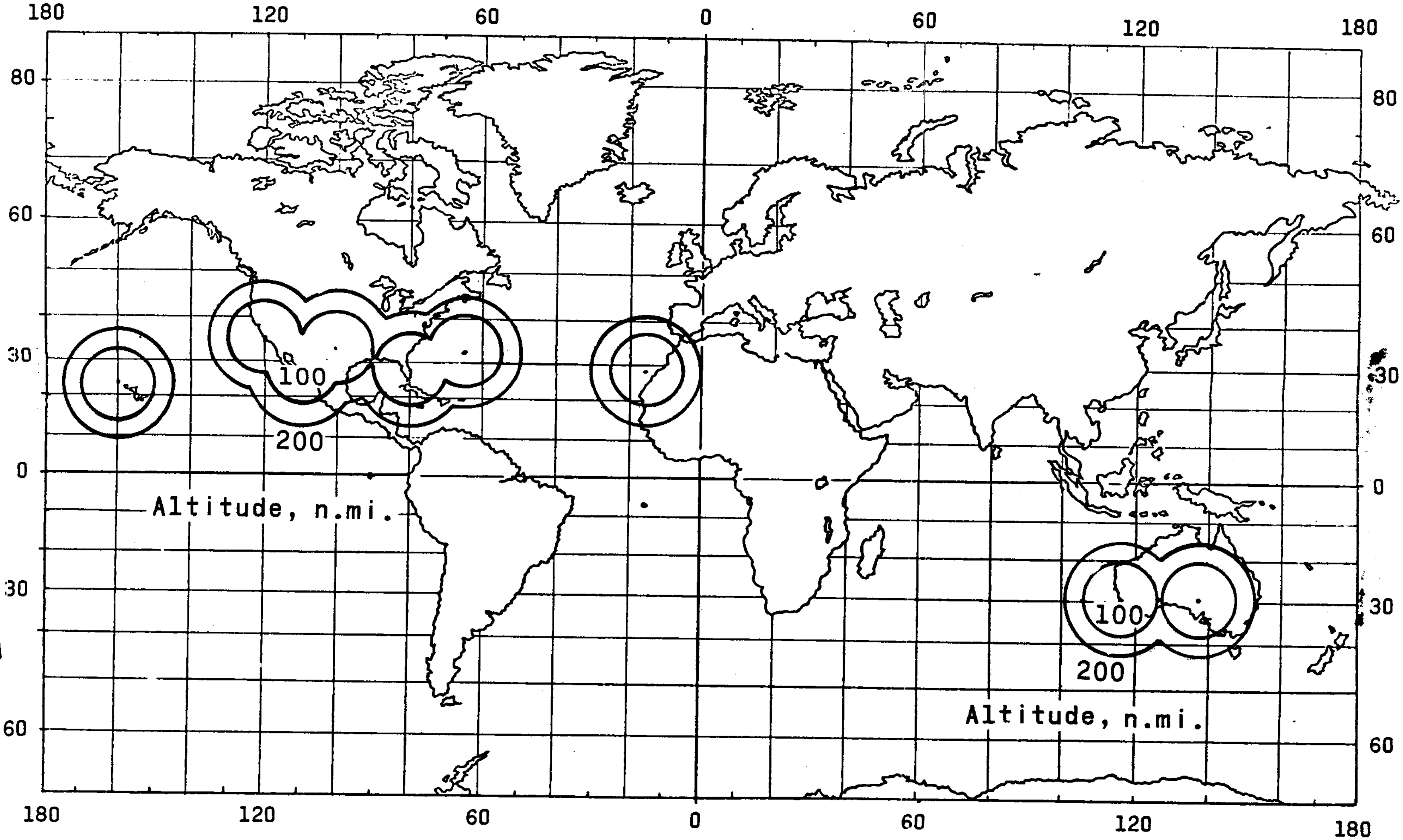

Figure 35- Coverage of Mercury tracking network for 5^{0} elevation angle.

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[redacted]

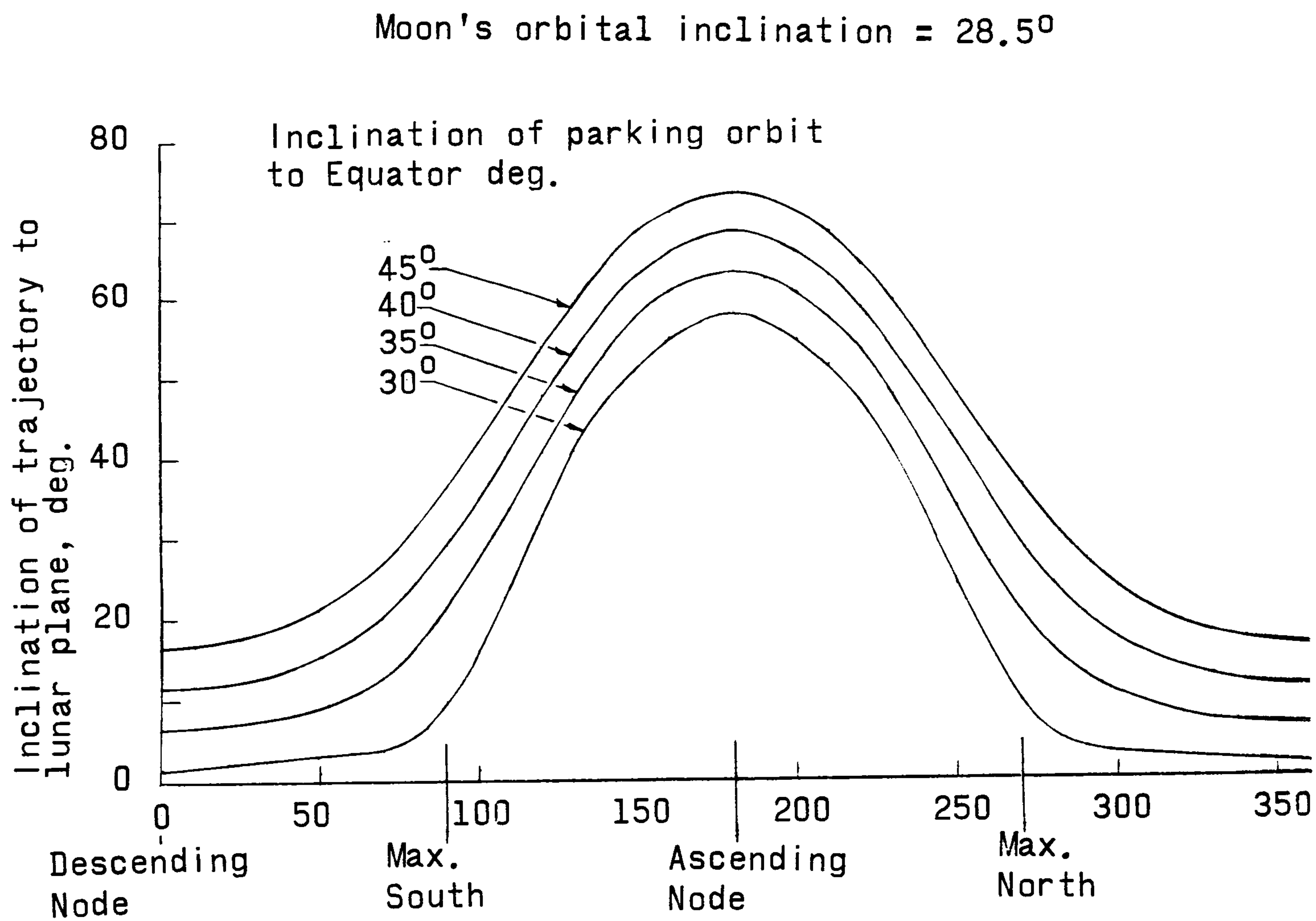

Figure 36 .- Inclination of trajectory to moon's orbital plane and equatorial plane.

[redacted]

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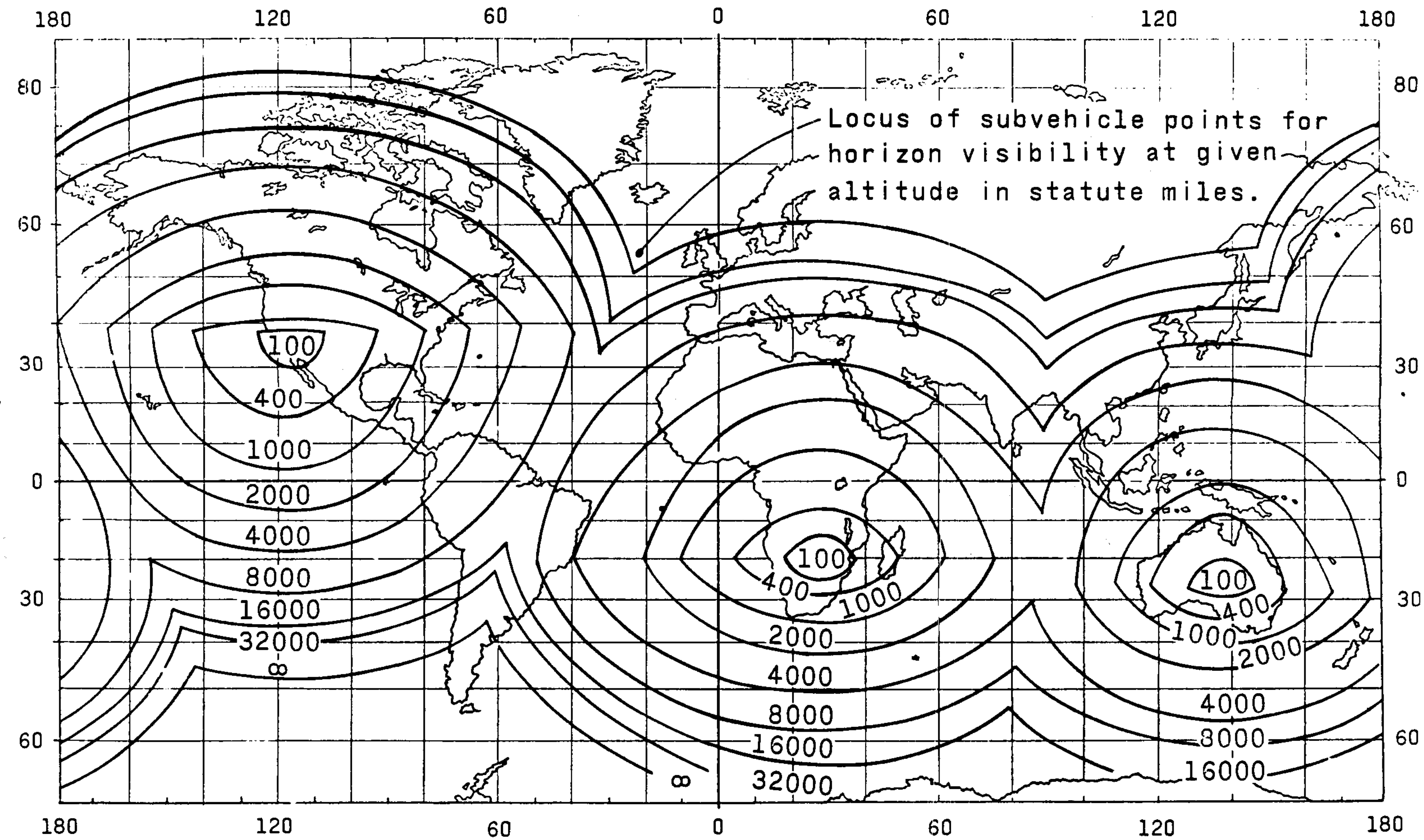

Figure 37- Deep Space Station coverage plots for a 5^0 terrain horizon mask

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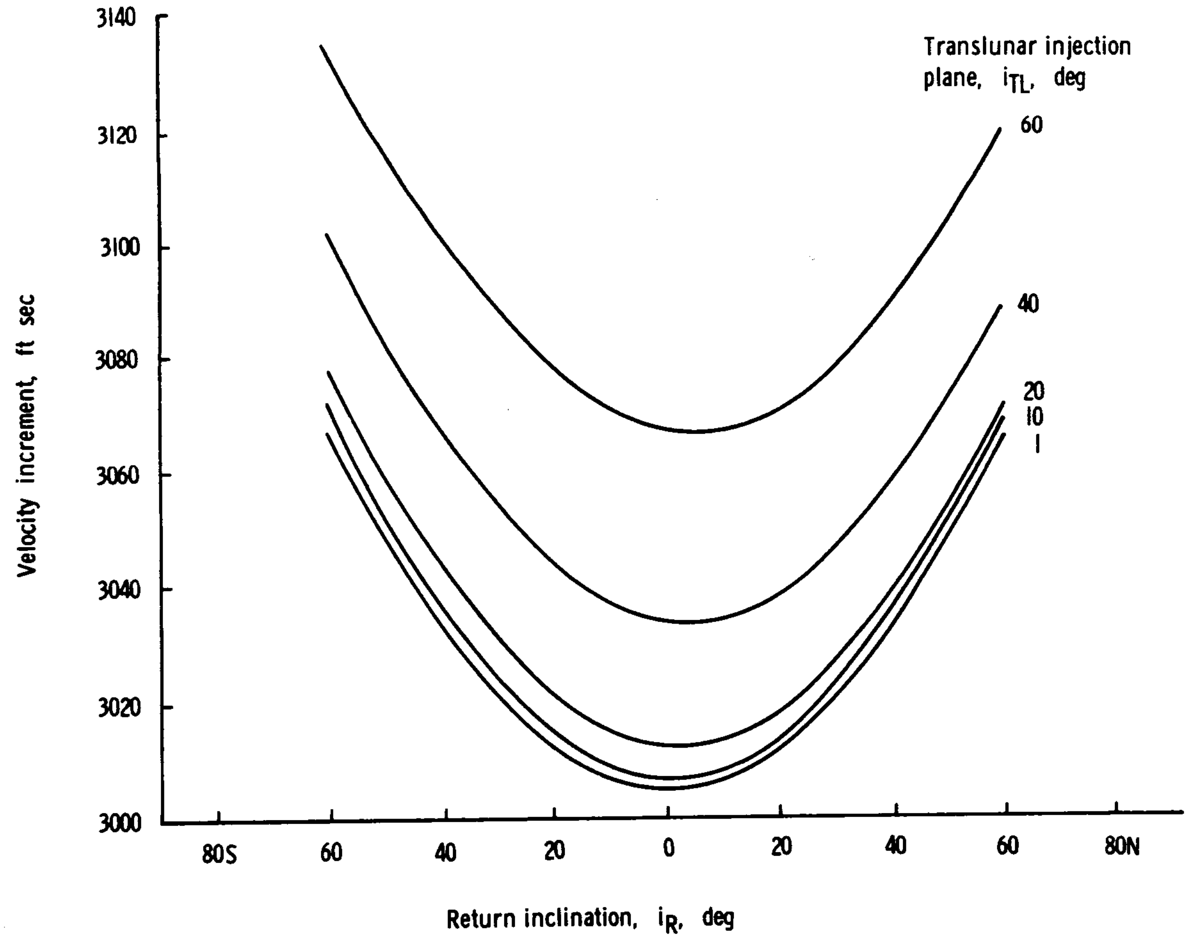
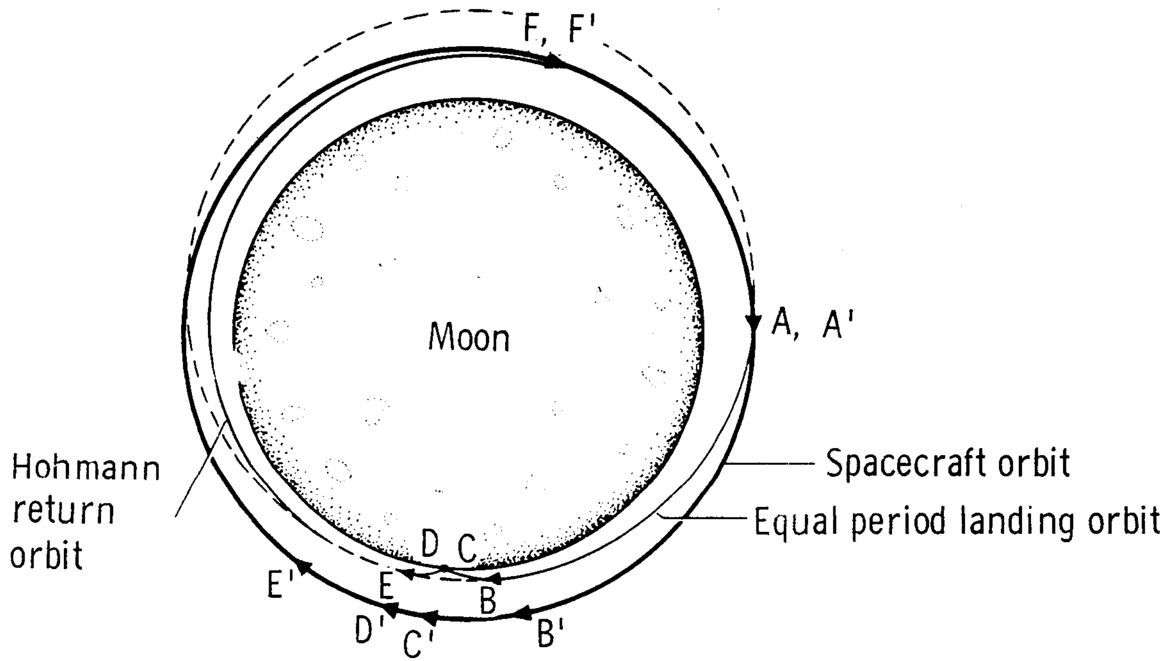


Figure 38- Velocity increments for establishing 100 n. m. lunar circular orbits from free return circumlunar trajectories.



A. Seperation of Lunar Module from Spacecraft
B. Initiation of landing maneuver
C. Start of hover
D. Abort from hover or takeoff from lunar surface
E. Insertion into return orbit
F. Rendezvous of spacecraft and Lunar Excursion Module

Figure 39. - Lunar landing technique via equal period transfer

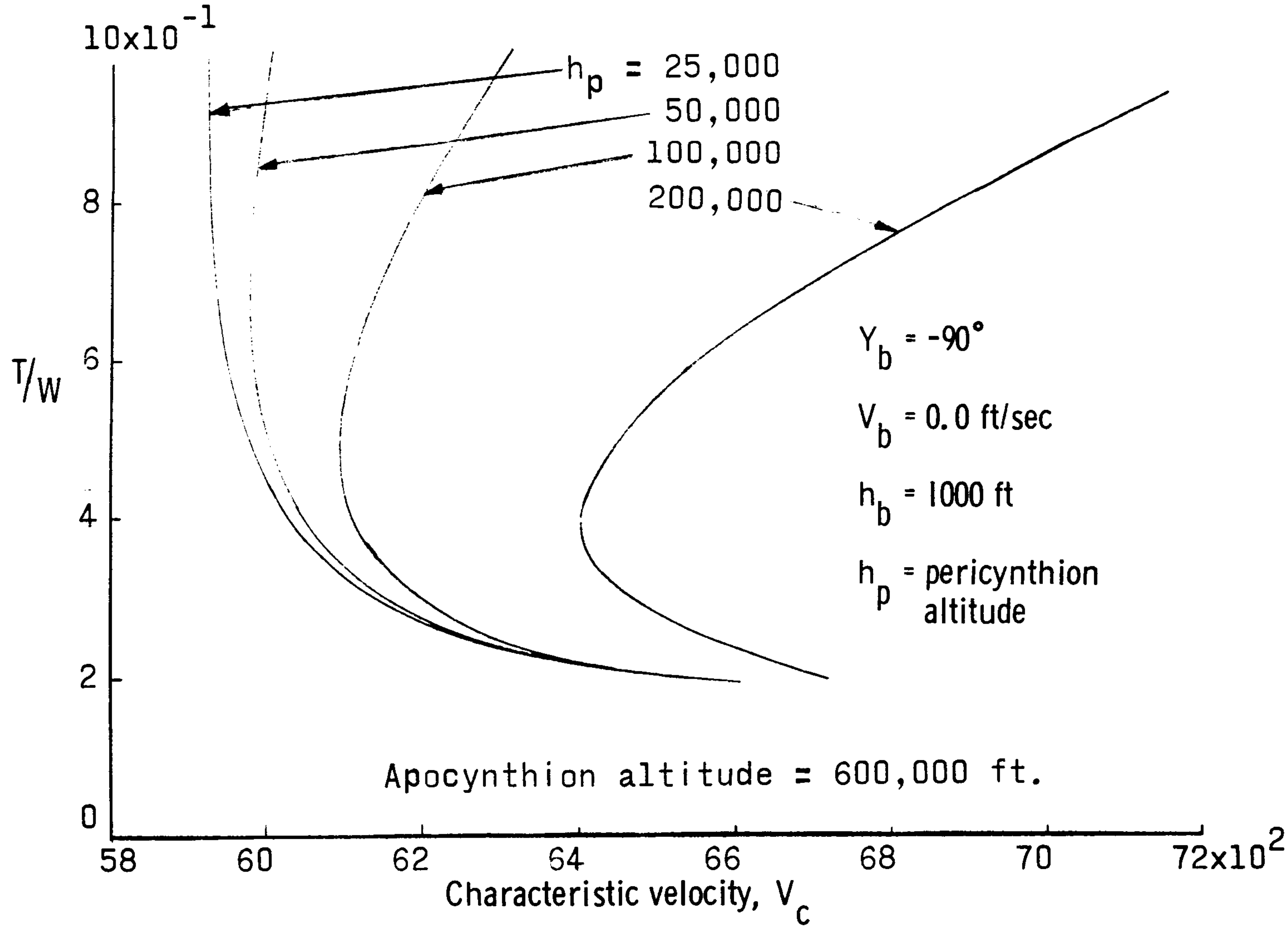


Figure 40. - Characteristics velocity for optimum lunar landings from elliptic orbits with various pericynthion altitudes.

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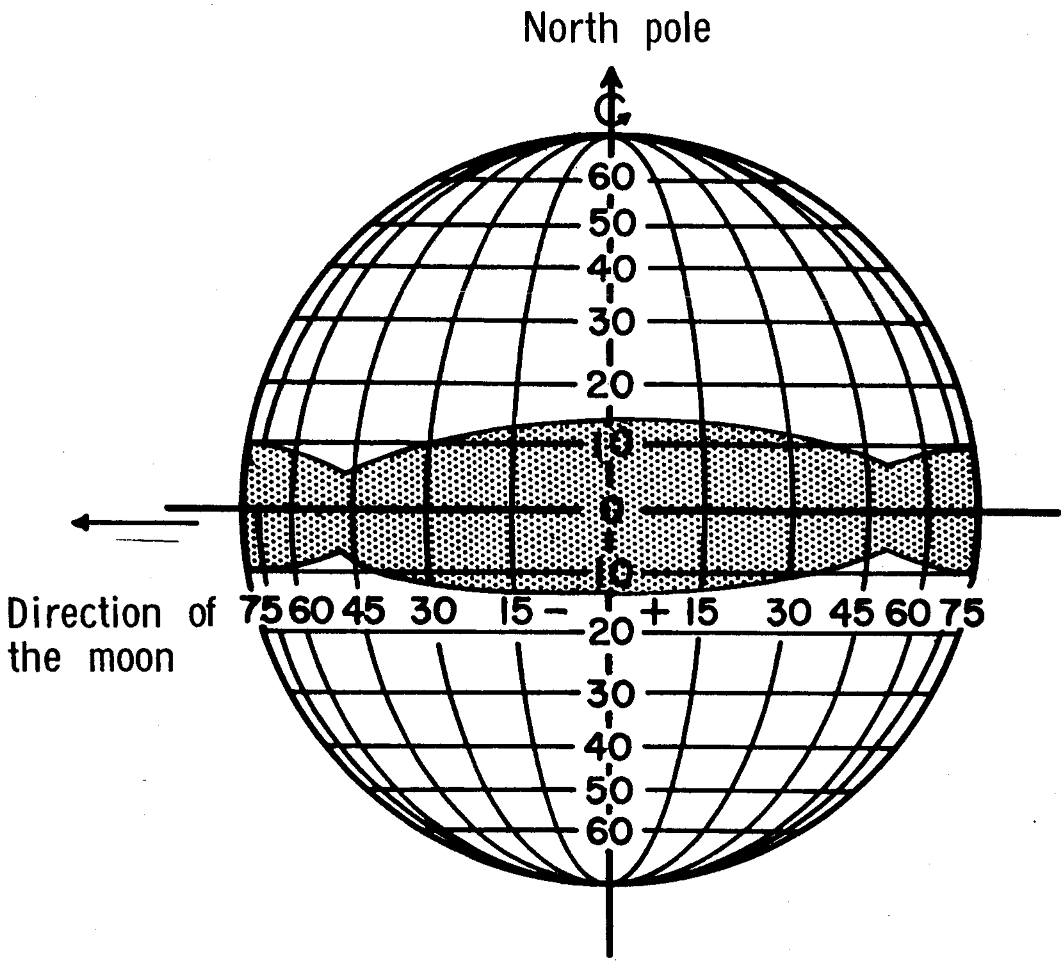

Figure 41. - Landing area from circumlunar trajectories without plane change

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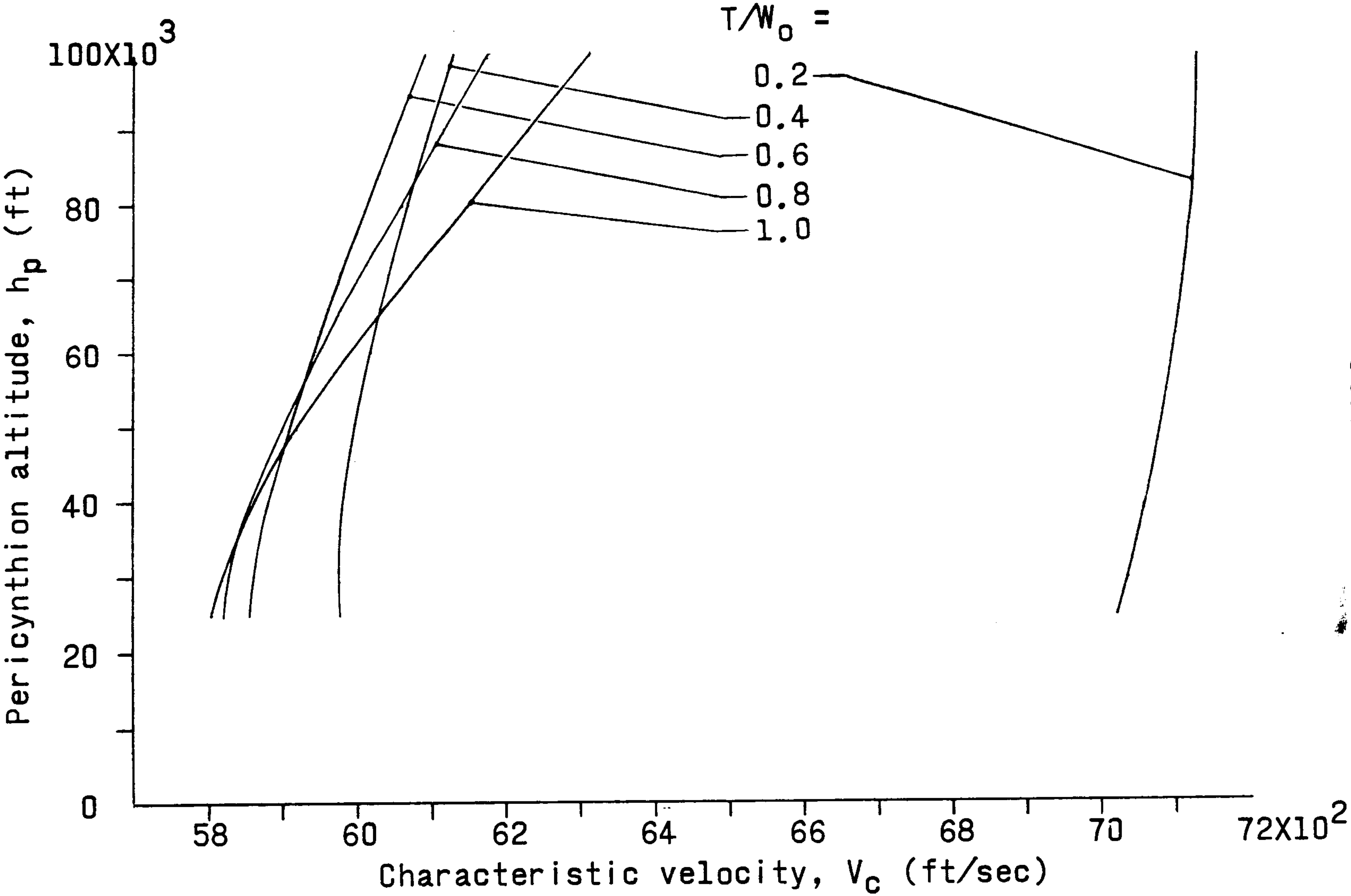
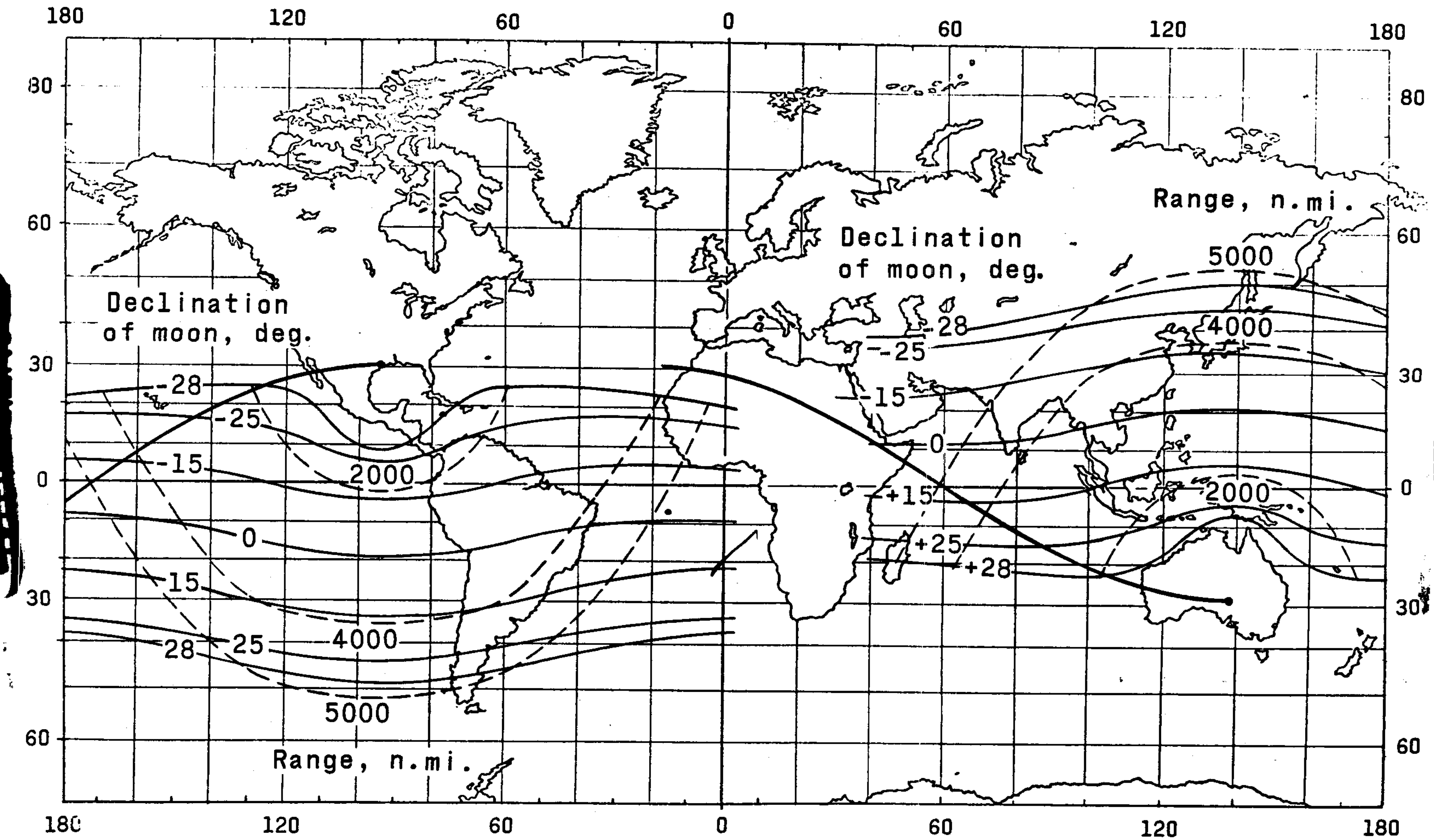


Figure 42.- Characteristic velocity for lunar launches to elliptic orbits with various T/W_o. Apocynthion altitude = 600,000 ft.

[redacted]

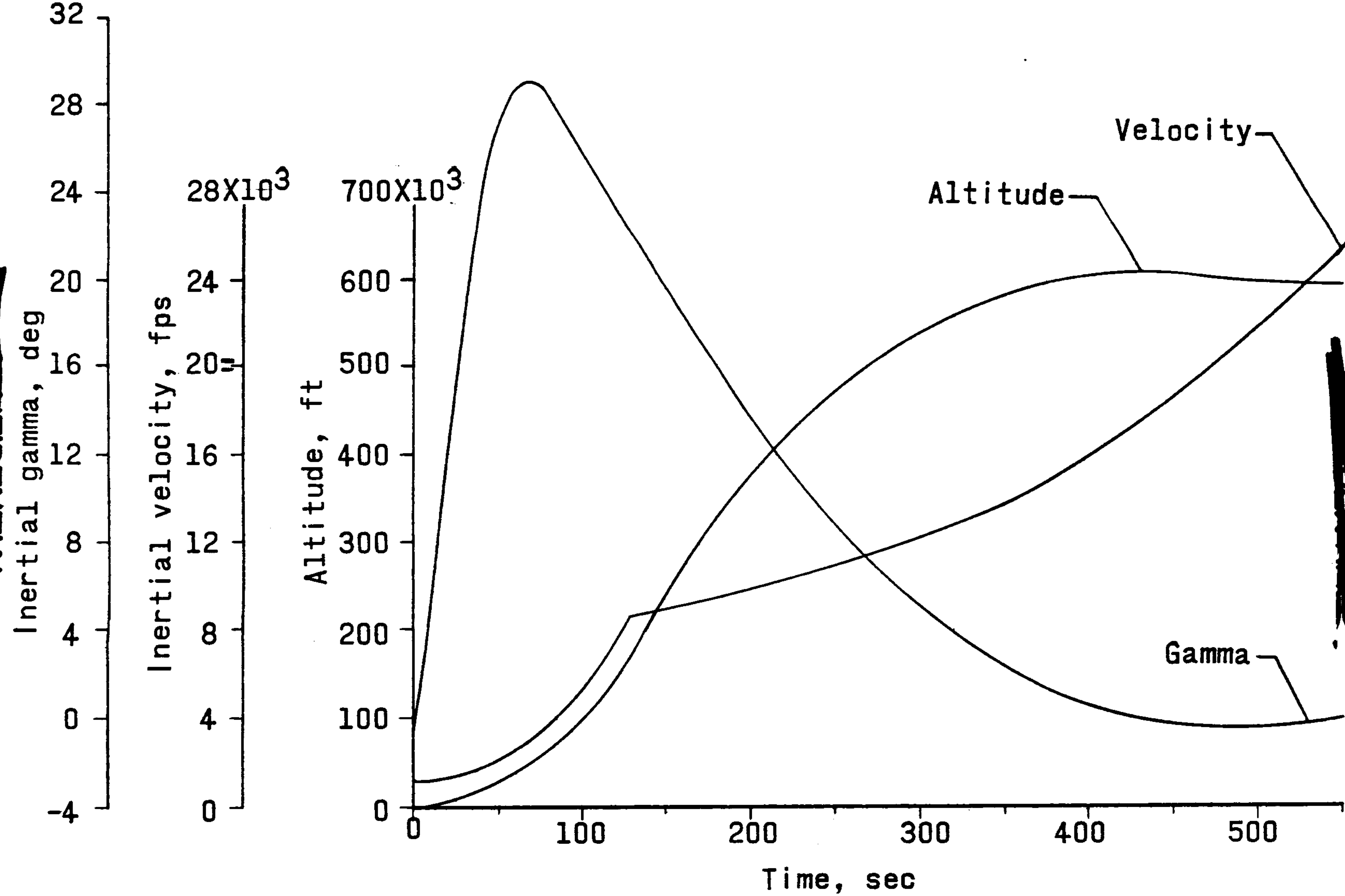
[redacted]



[redacted]

Figure 43- Locus of reentry points for landing sites in U. S. A. and Australia.

[redacted]

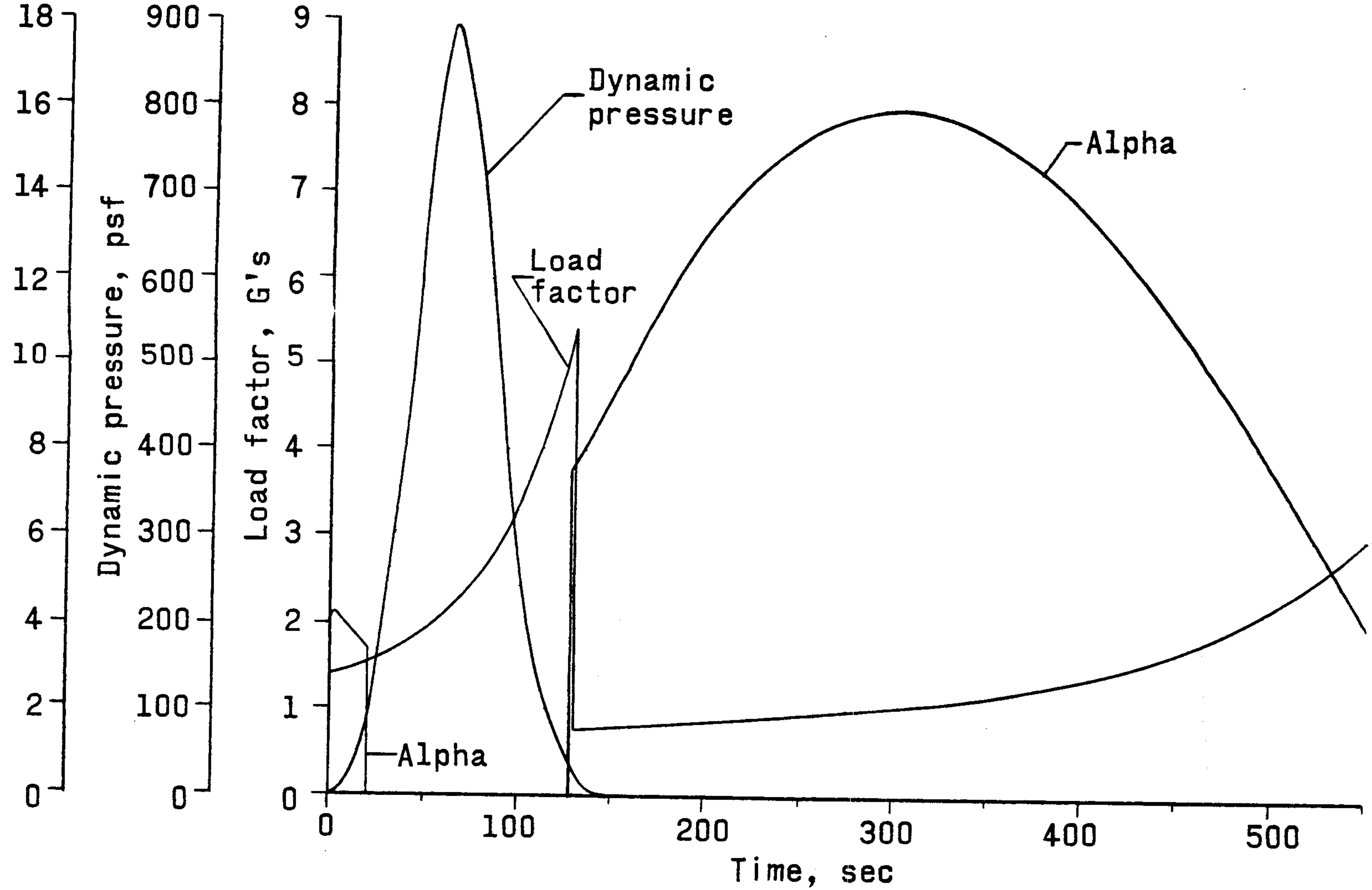


(a) Flight path.

Figure 44.- Time history from lift-off to parking orbit.

[redacted]

[redacted]



(b) Loads.

Figure 44.- Concluded.

[redacted]

[redacted]

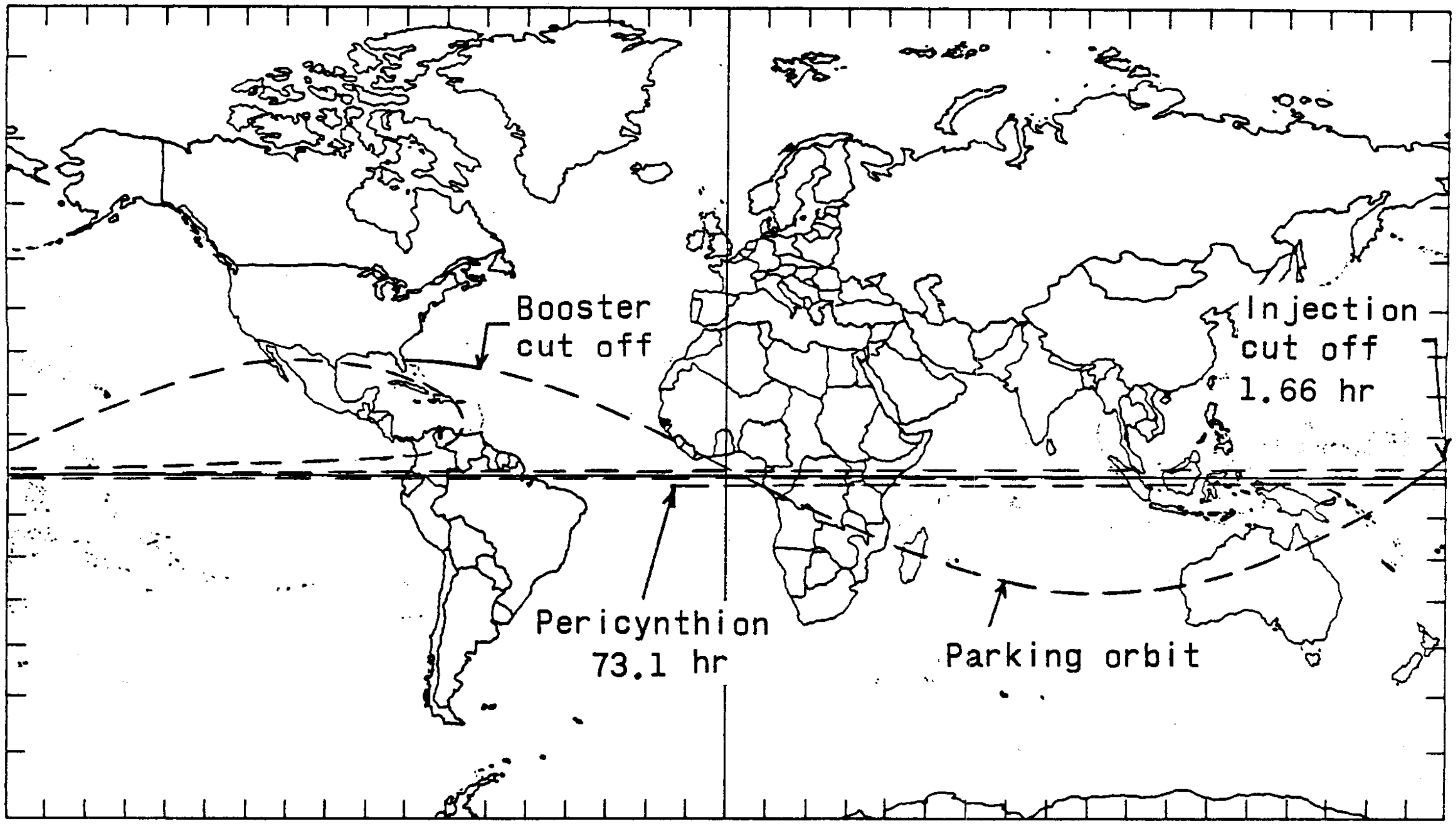


Figure 45.- Earth track for lunar flight plan.

[redacted]

[redacted]

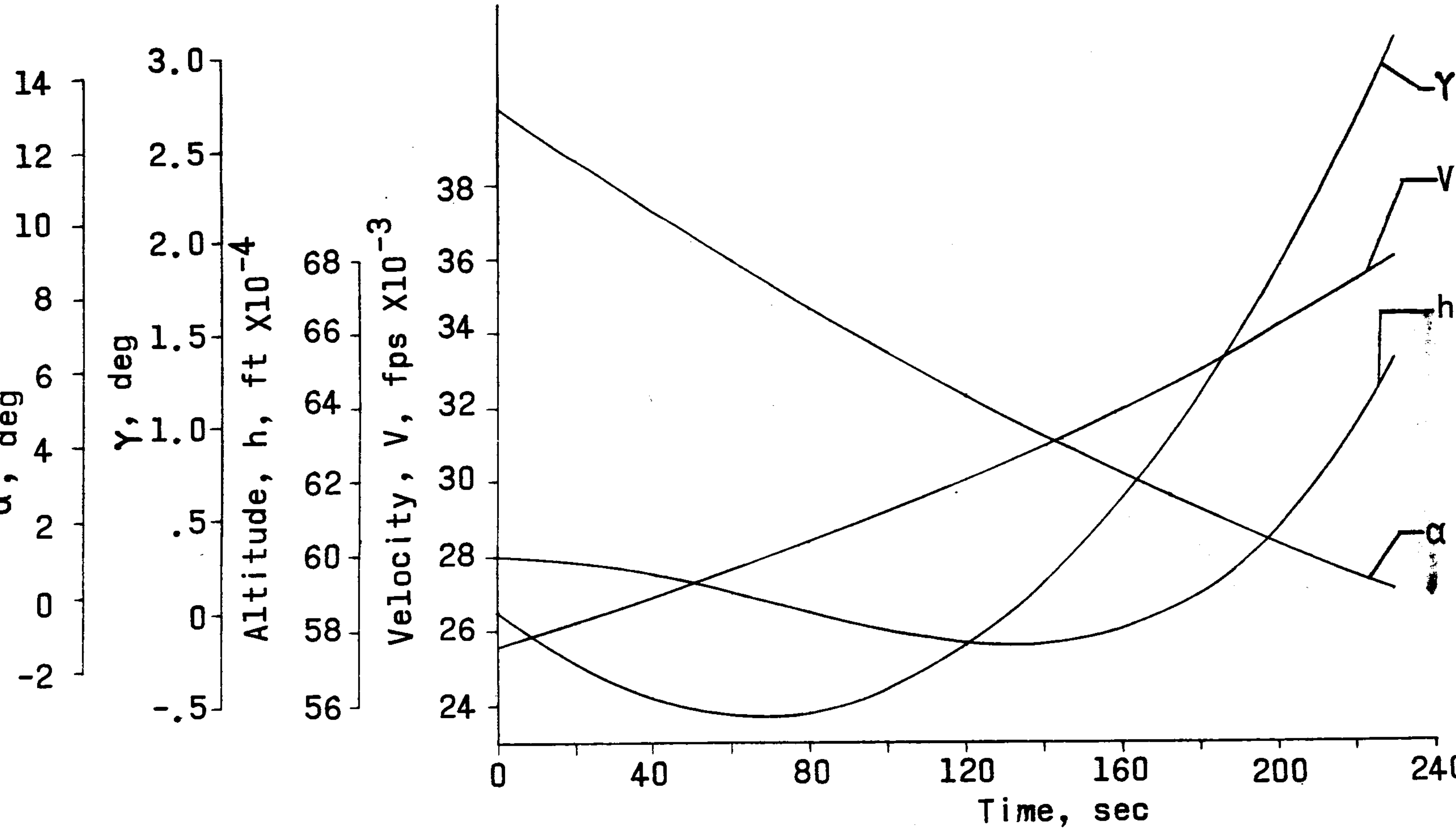


Figure 46.- Time history of transfer from parking orbit to translunar trajectory.

[redacted]

[redacted]

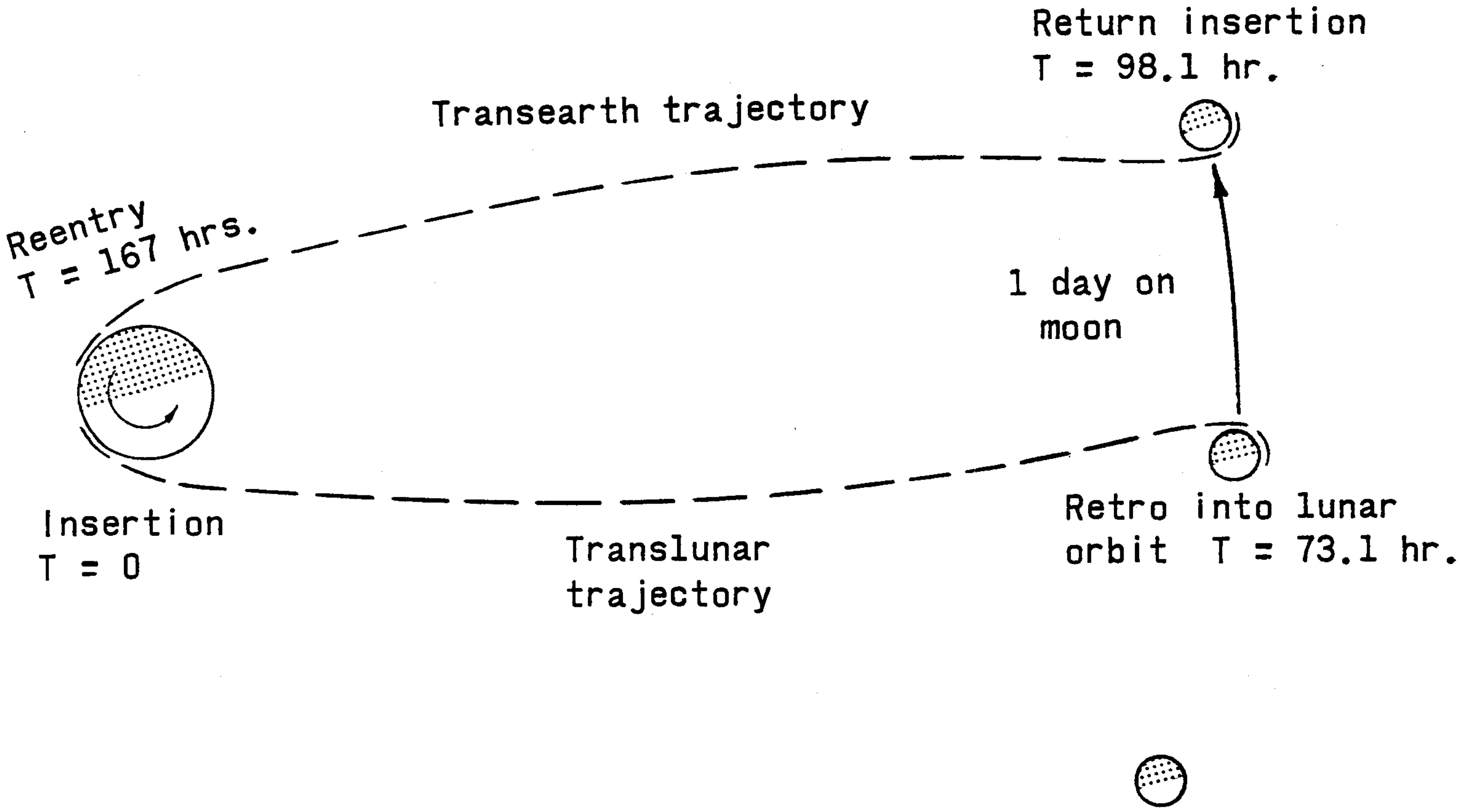


Figure 47.- Translunar and transearth trajectories shown in the inertial Earth-Moon system.

[redacted]

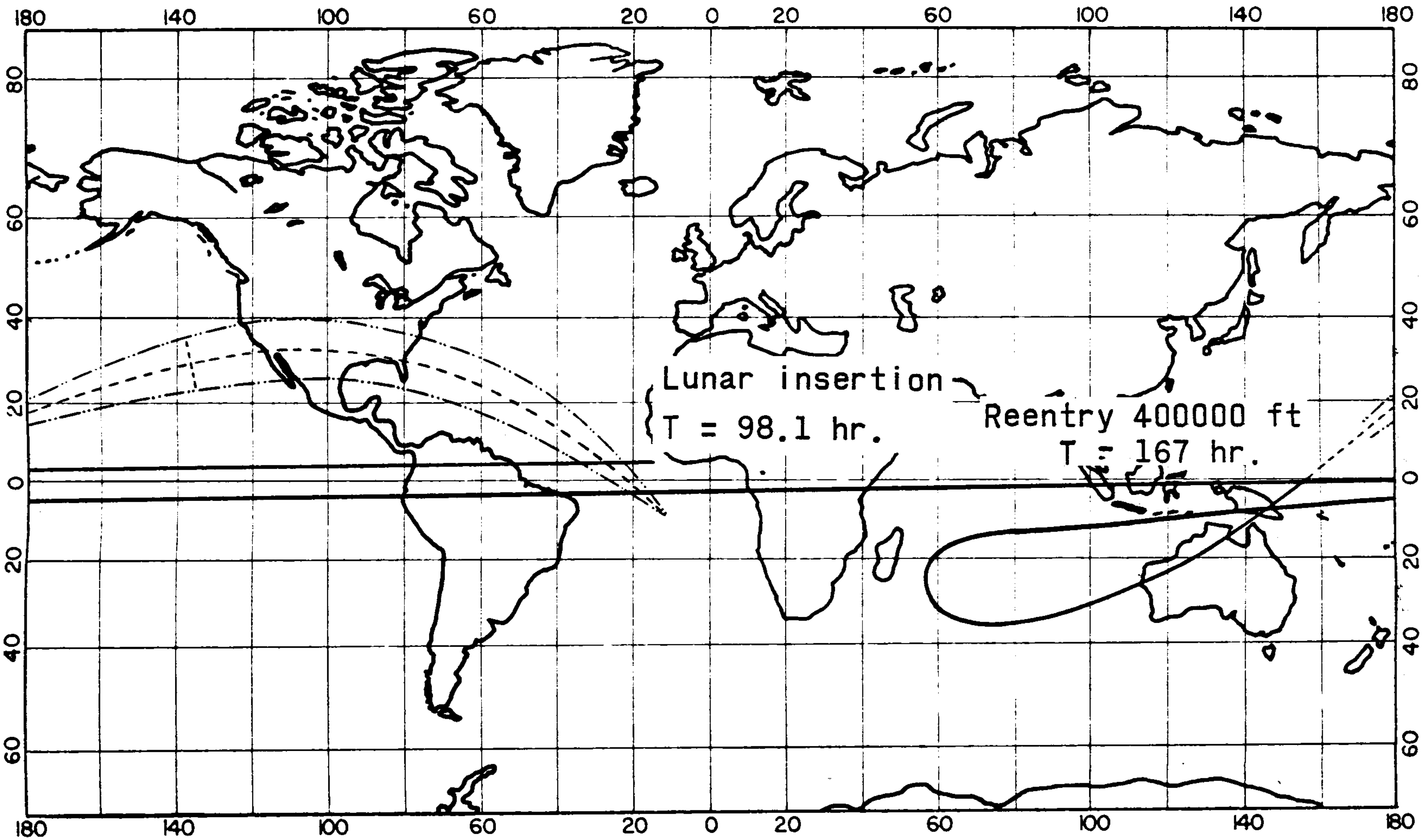


Figure 48.- Earth track of transearth and reentry phases.

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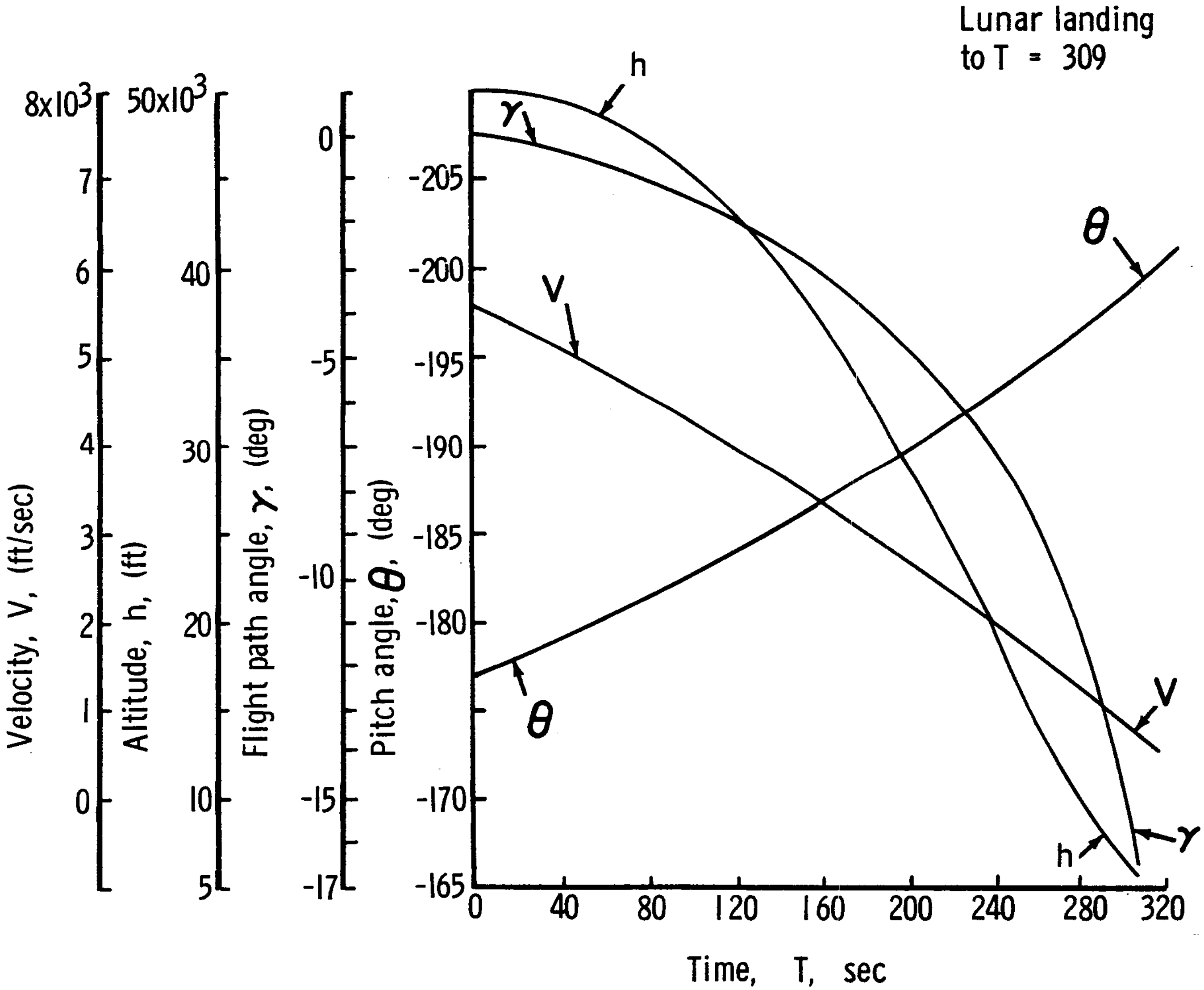

Figure 49 (a). - Lunar landing trajectory
$I_{sp} = 305$, $T\ W_0 = 0.4$

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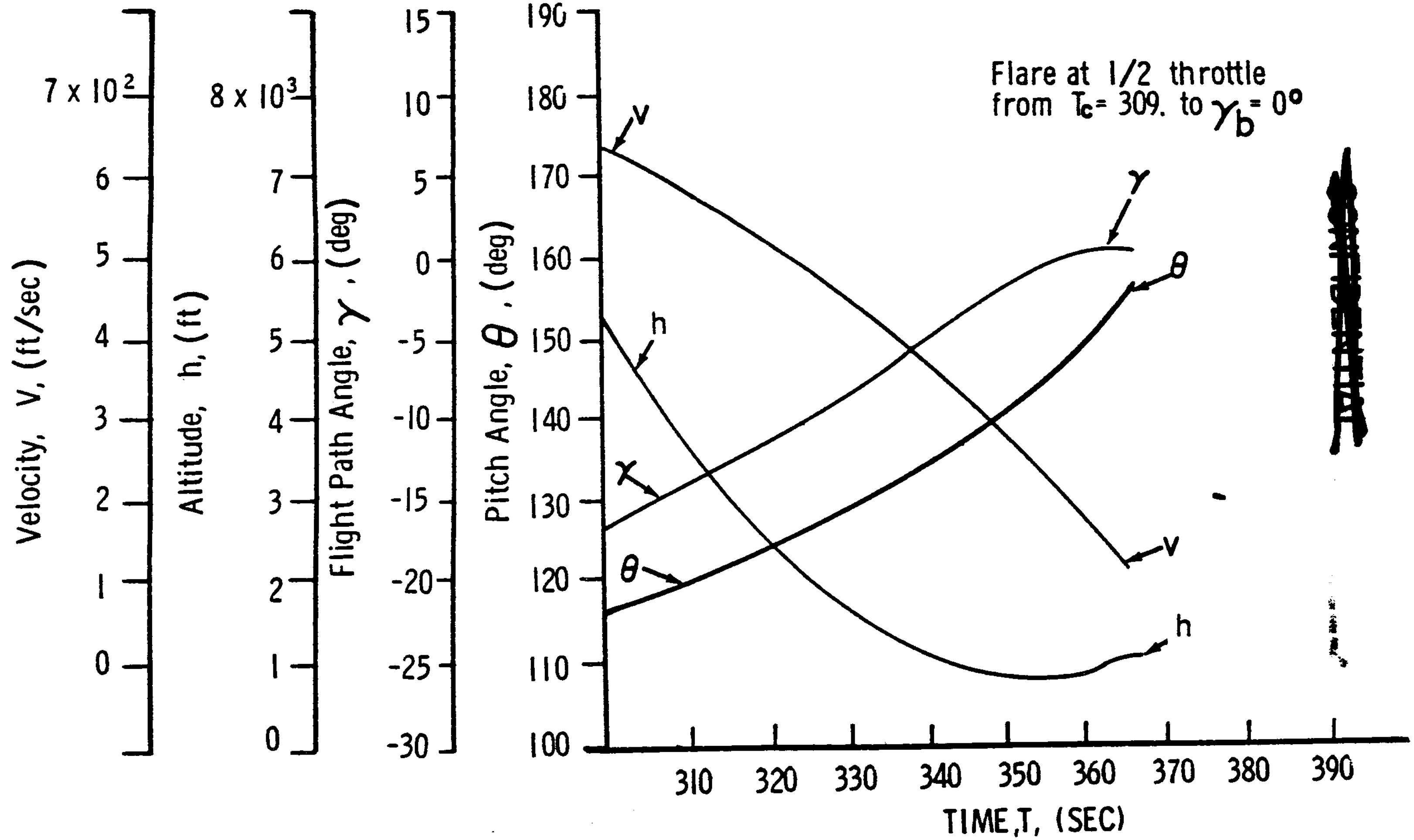

Figure 49 (b). - Lunar landing trajectory (Concluded)

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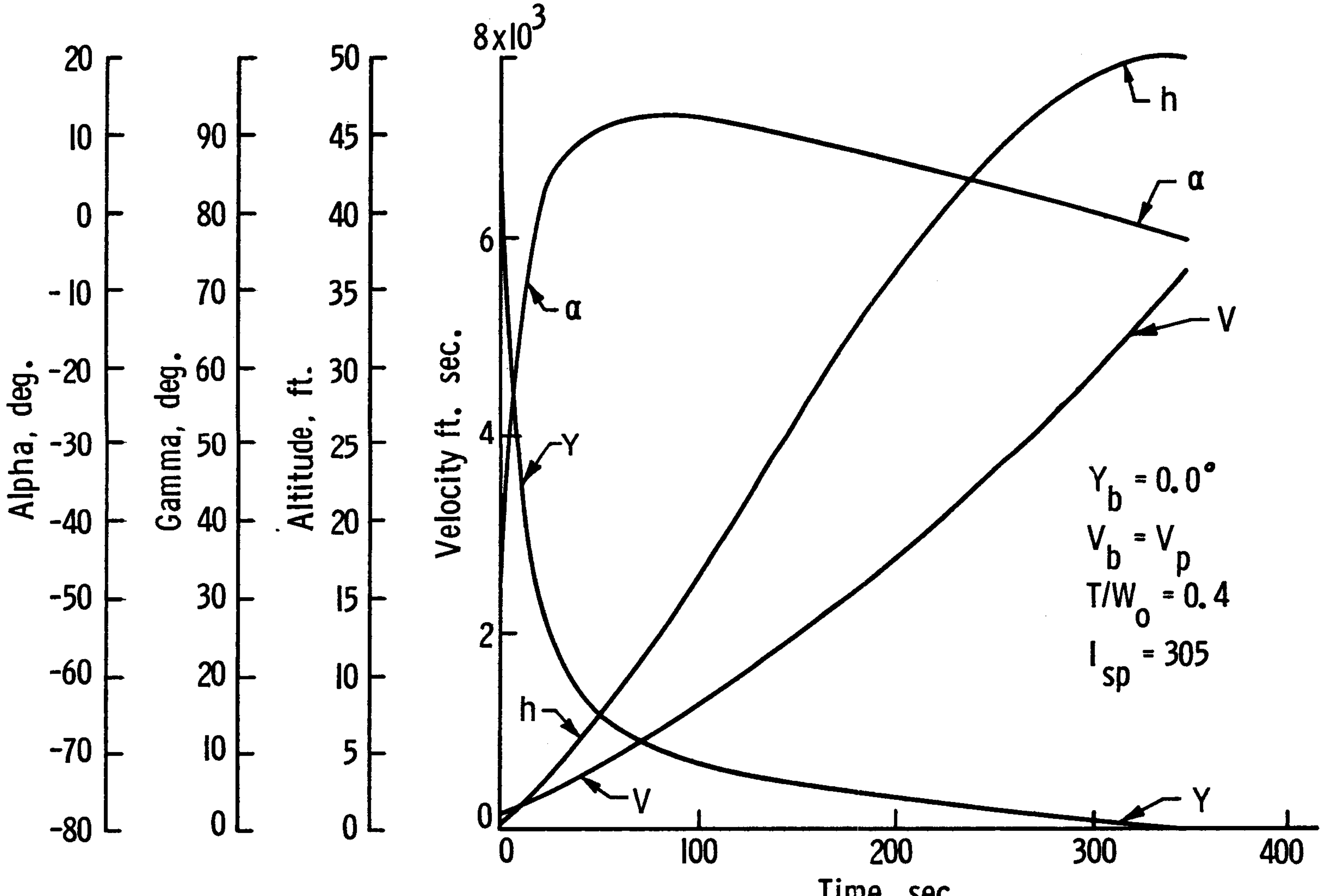

Figure 50. - Time history for optimum lunar launch to 50,000 ft. pericynthion, apocynthion altitude = 600,000 ft.

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[redacted]

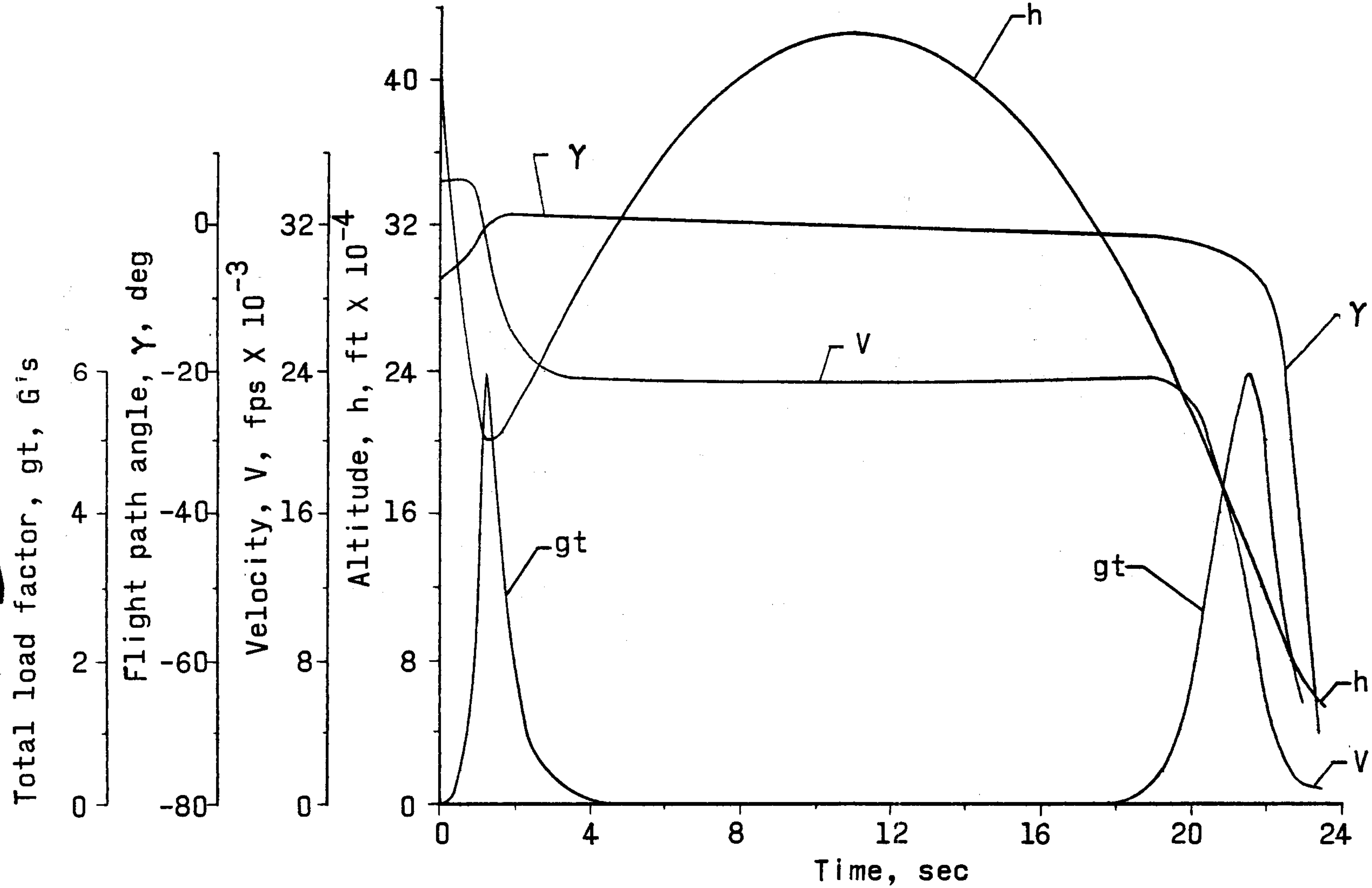


Figure 5l.- Time history from reentry to near-landing.

[redacted]

[redacted]

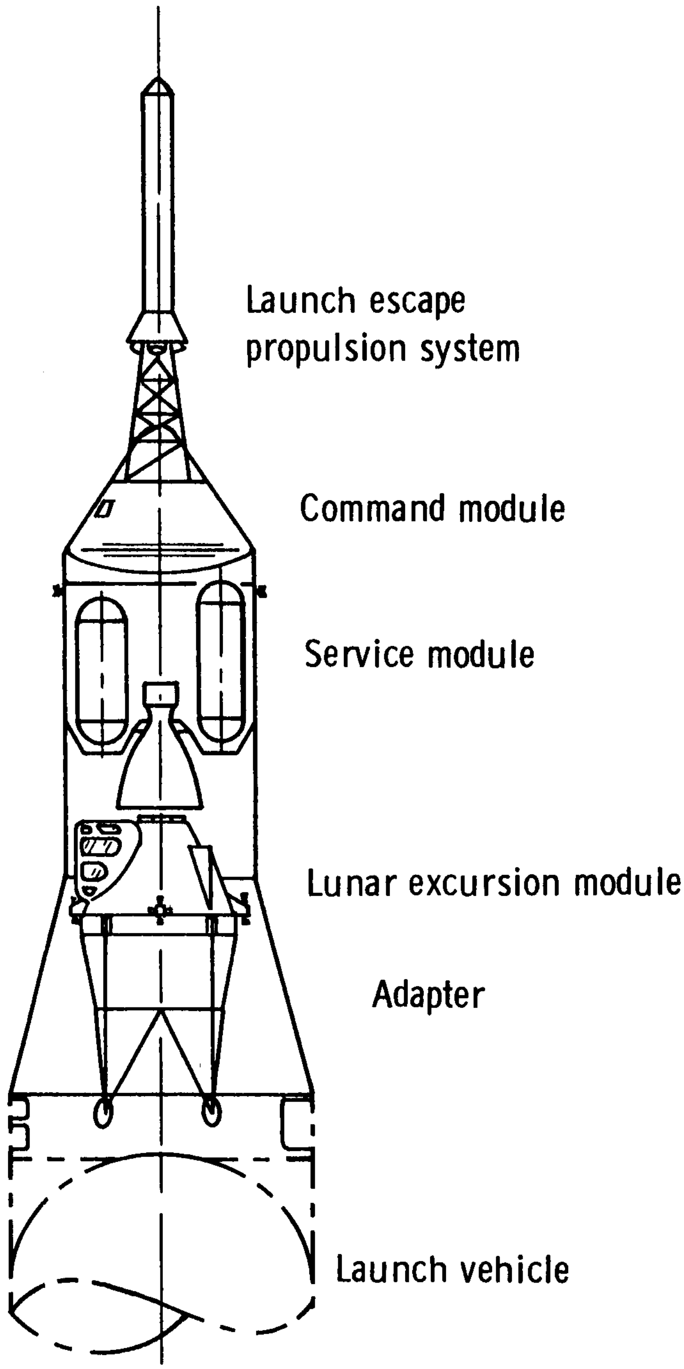


Figure 52. - General arrangement-
lunar landing configuration

[redacted]

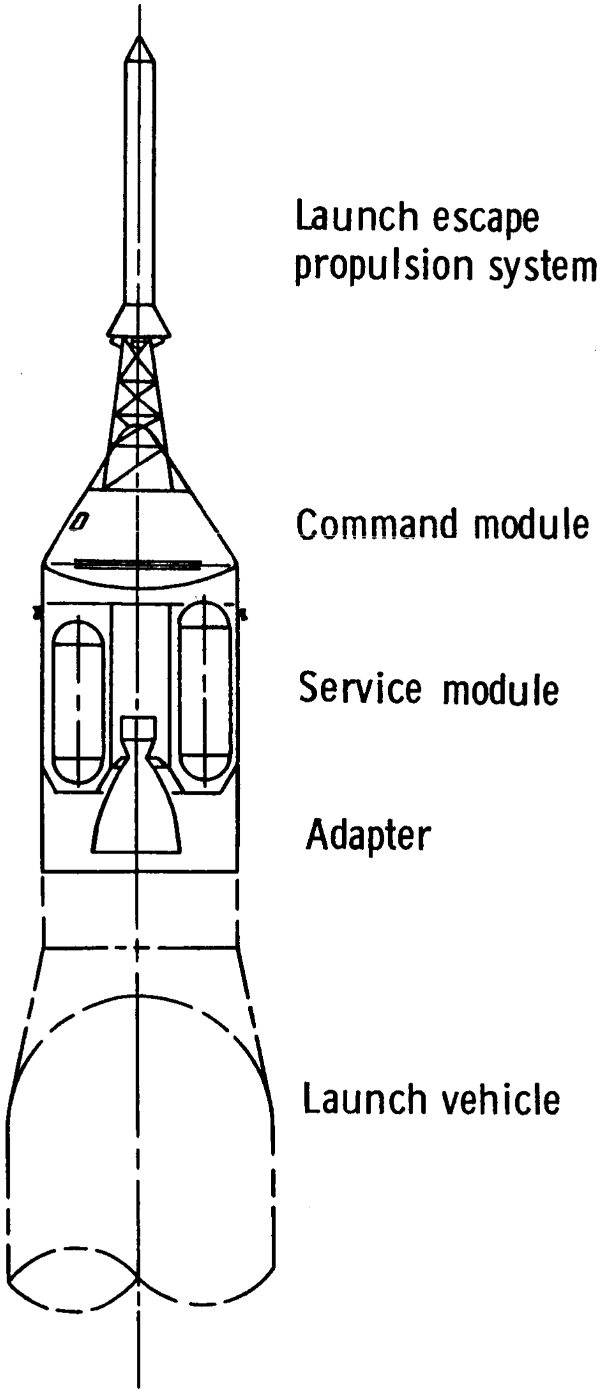


Figure 53. - General arrangement -
earth orbital configuration.

[redacted]

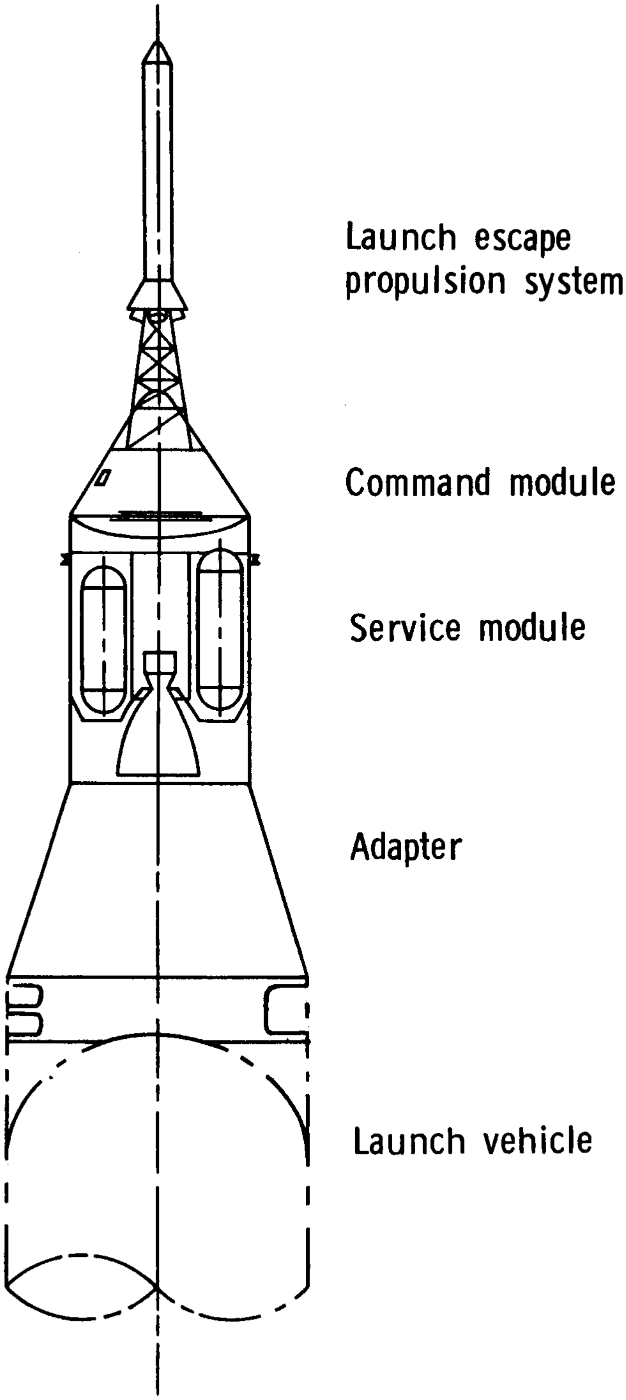


Figure 54.- General arrangement - circumlunar configuration.

[redacted]

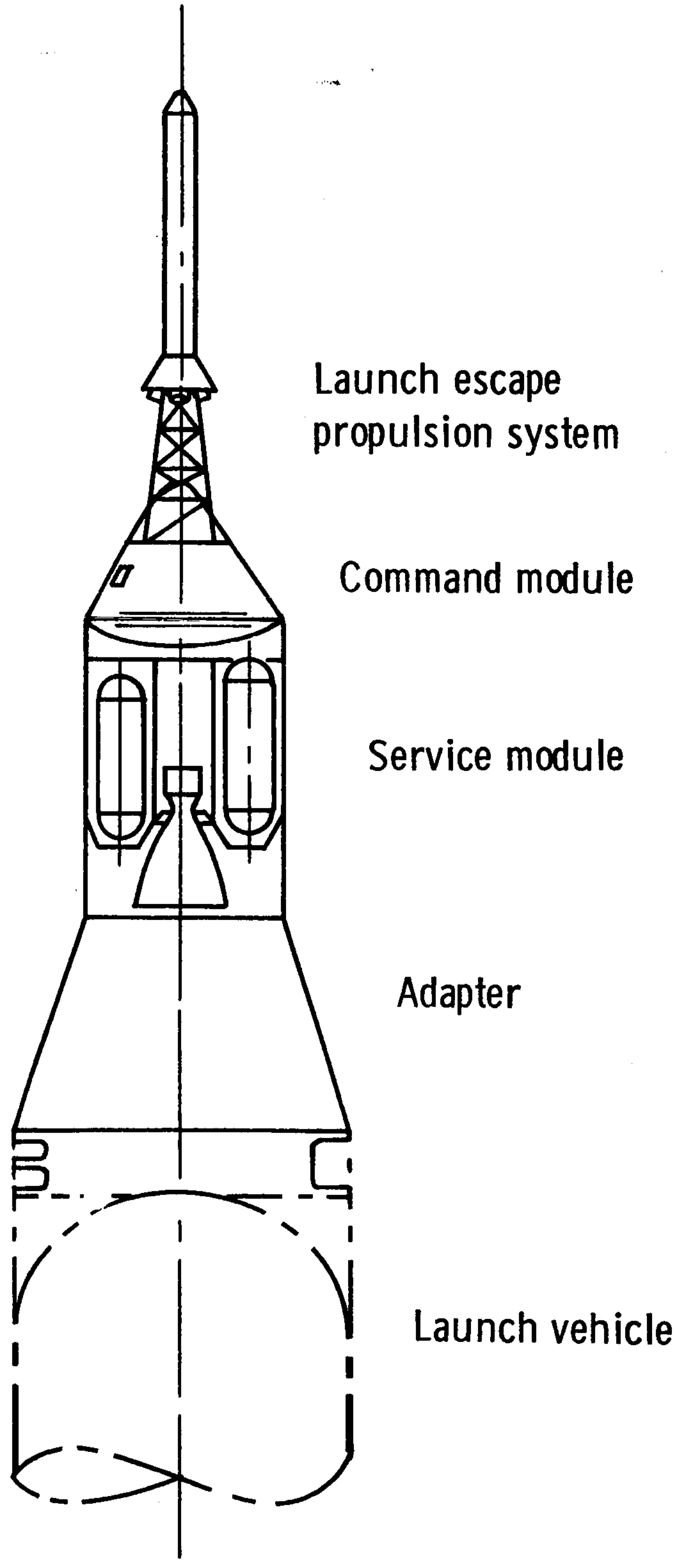


Figure 55. - General arrangement -
lunar orbital configuration.

[redacted]

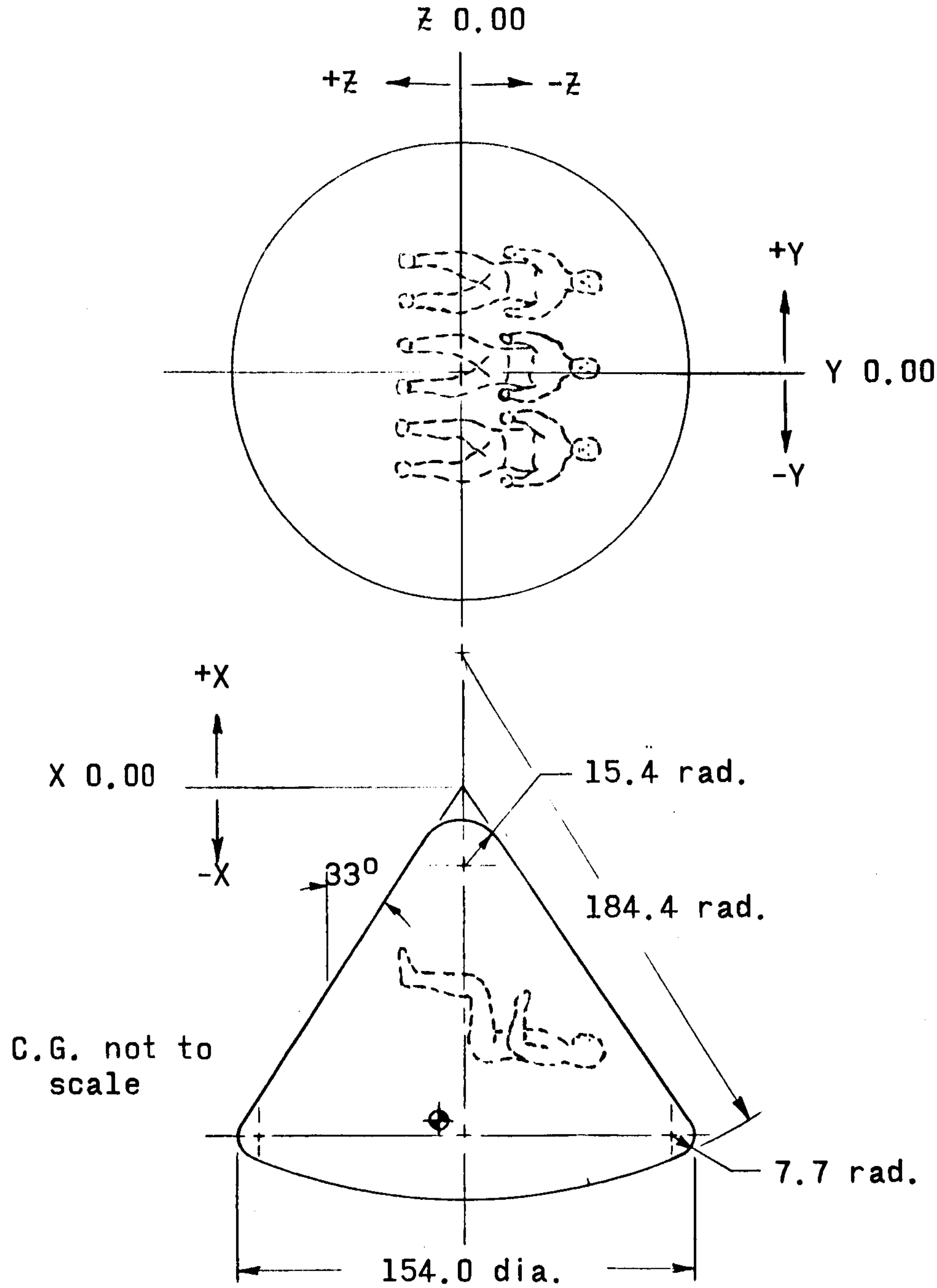


Figure 56.- Command module nominal geometry.

[redacted]

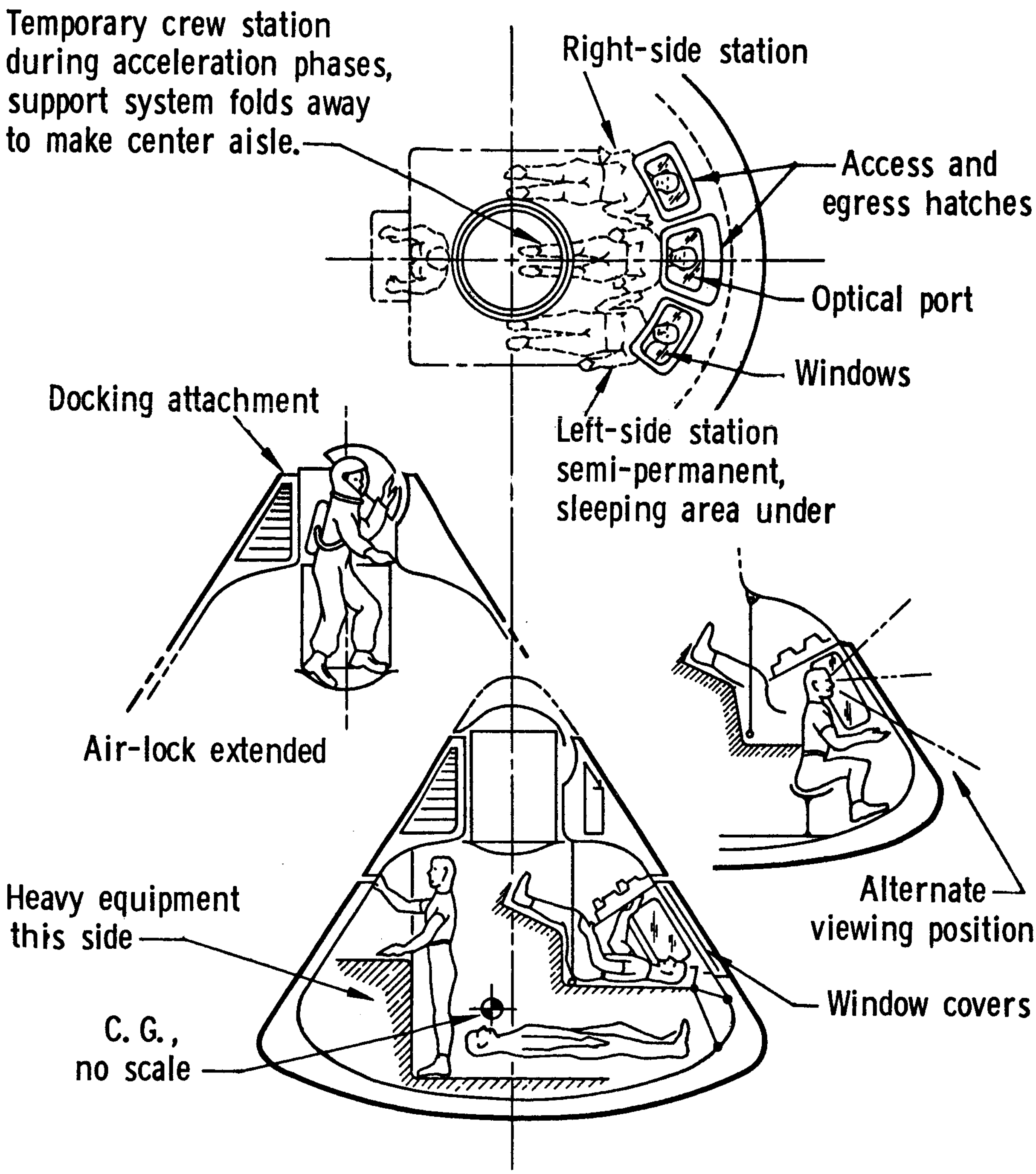


Figure 57.-Command module-Inboard profile, activity areas.

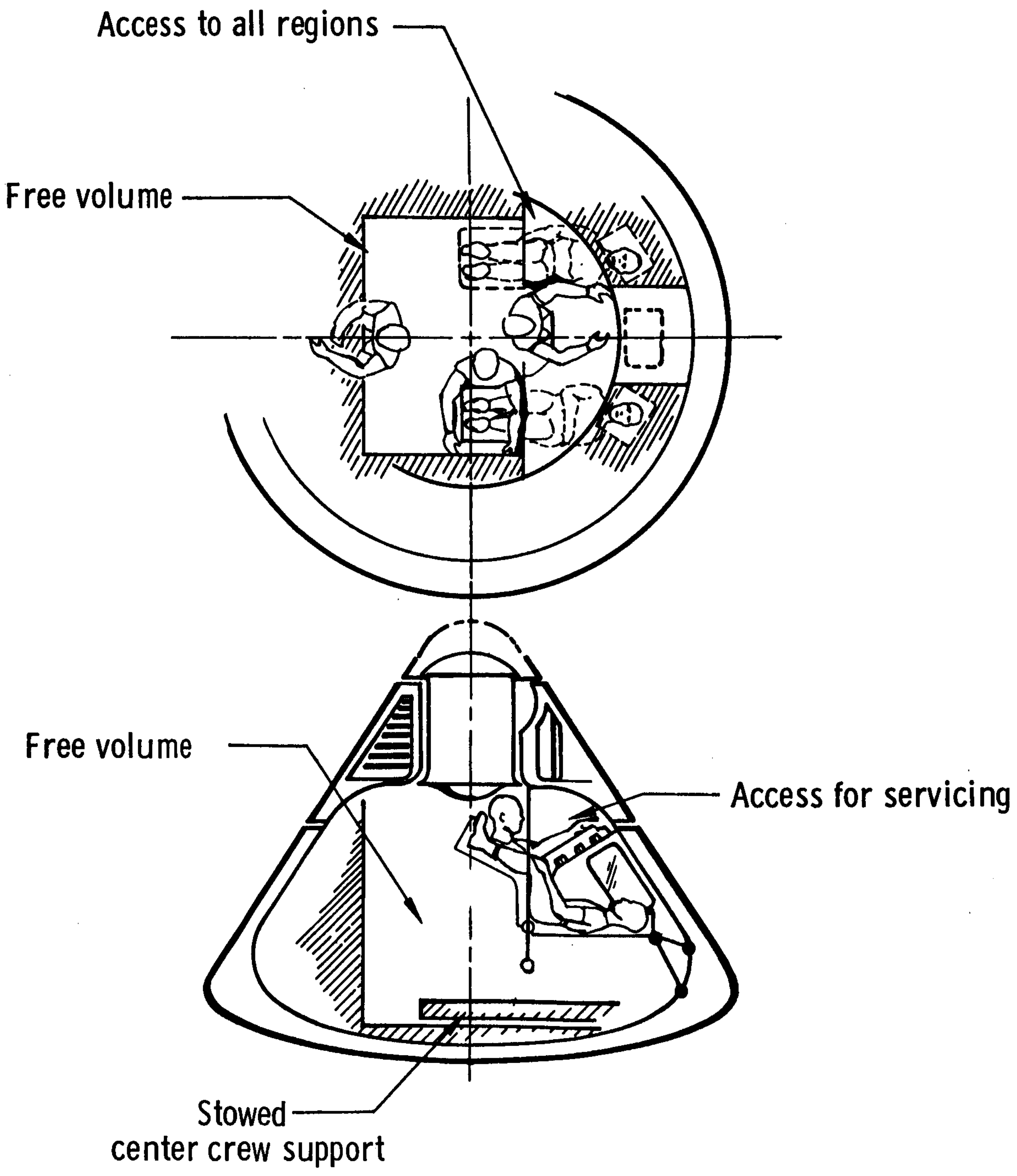


Figure 58. - Command module - Inboard profile, volume utilization.

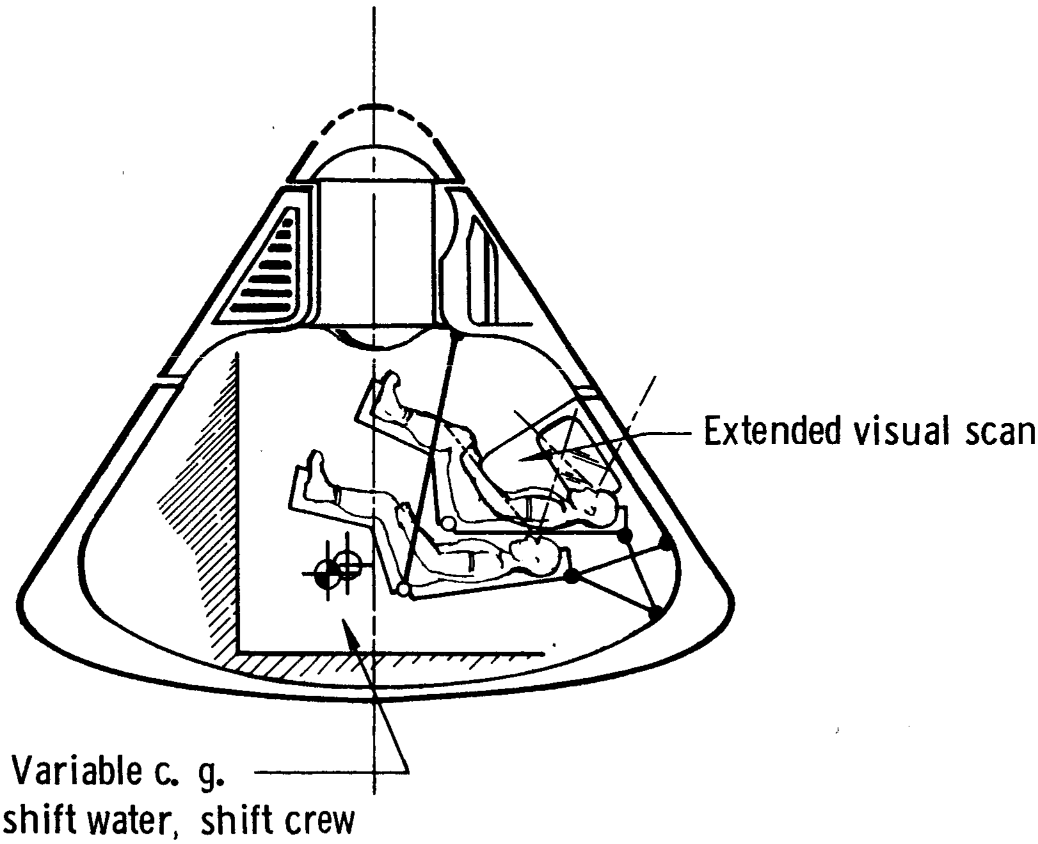


Figure 59. - Command module - Inboard profile, display coverage and center of gravity control.

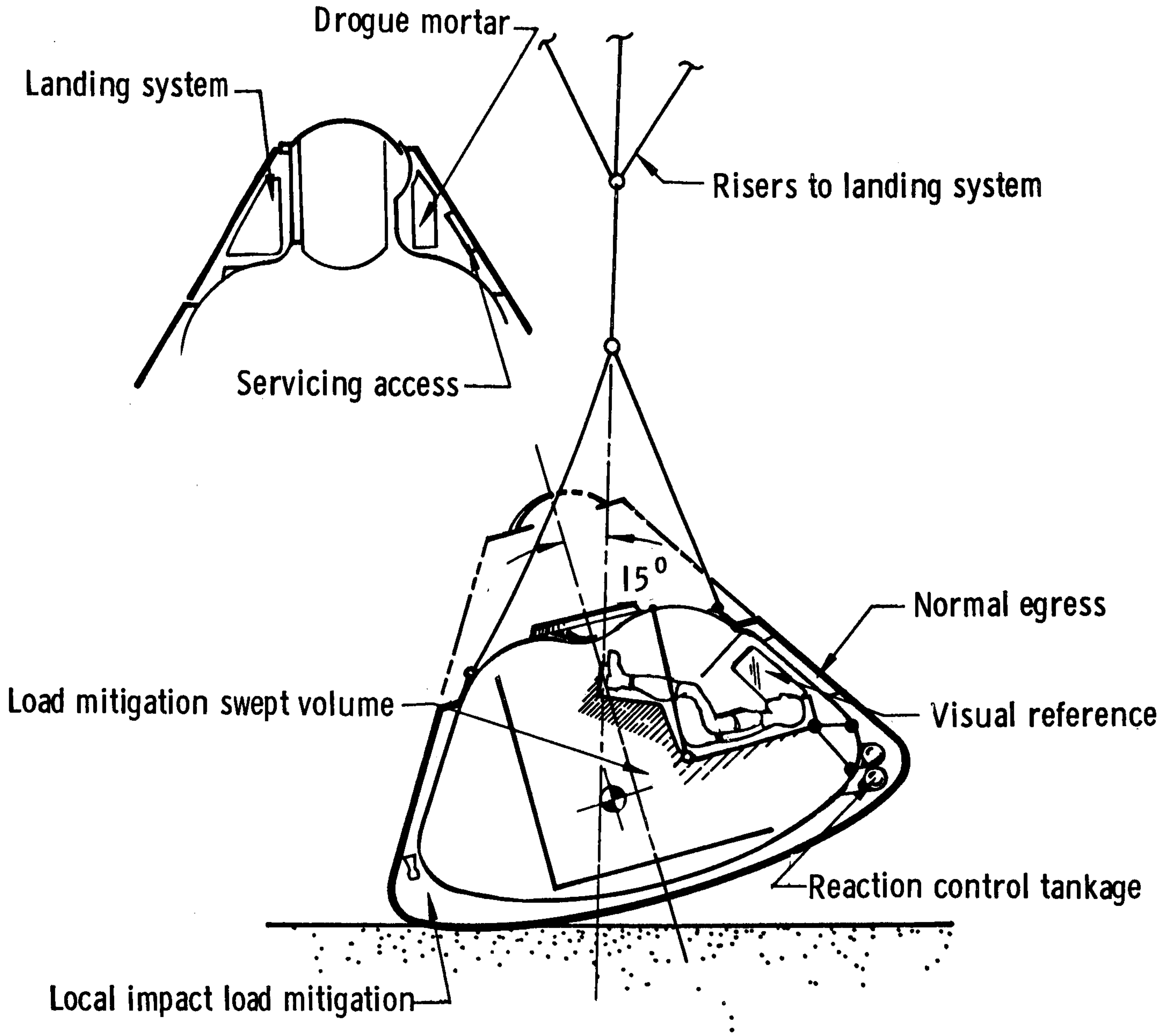


Figure 60. - Command module - Inboard profile, landing considerations.

[redacted]

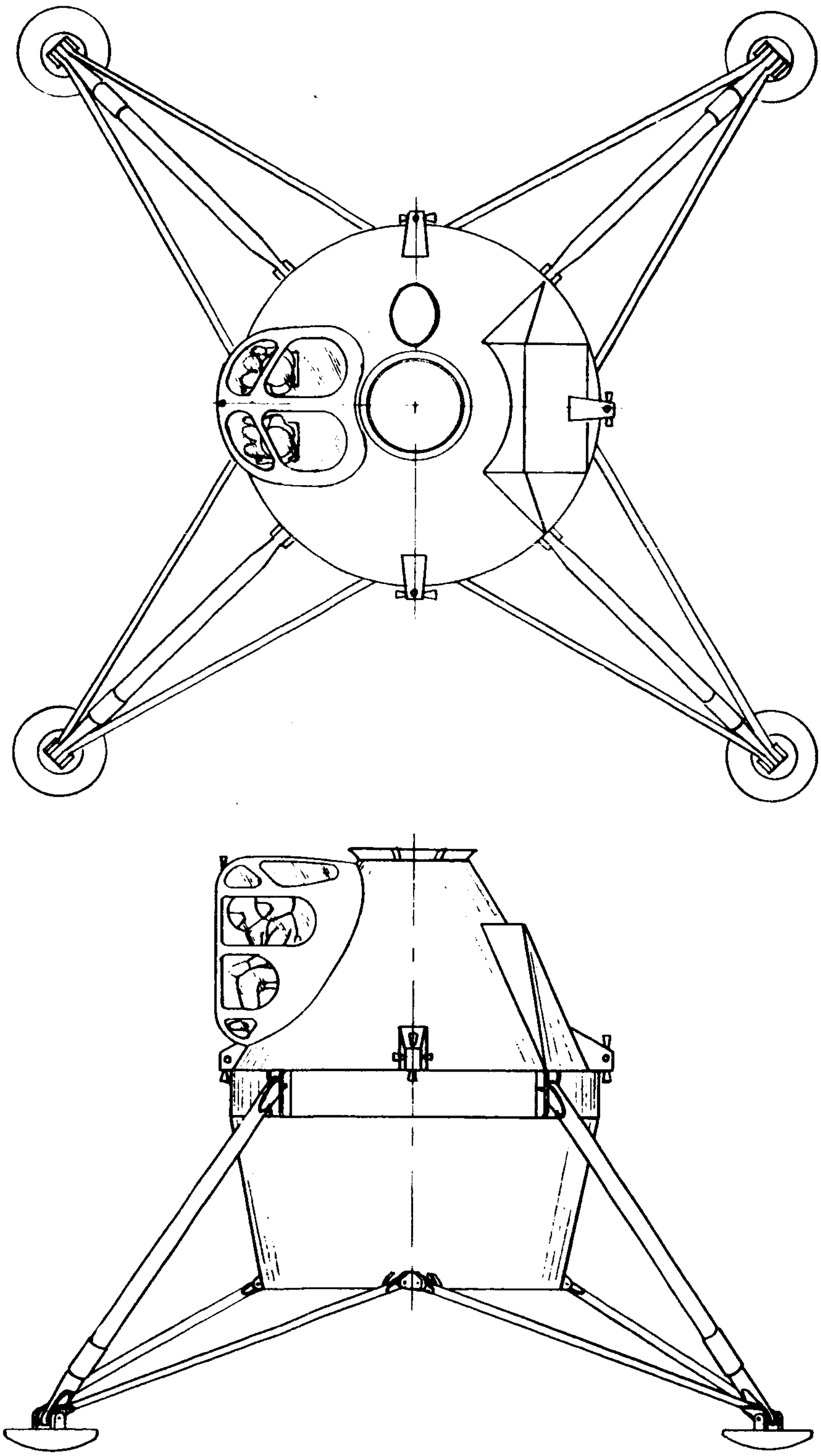
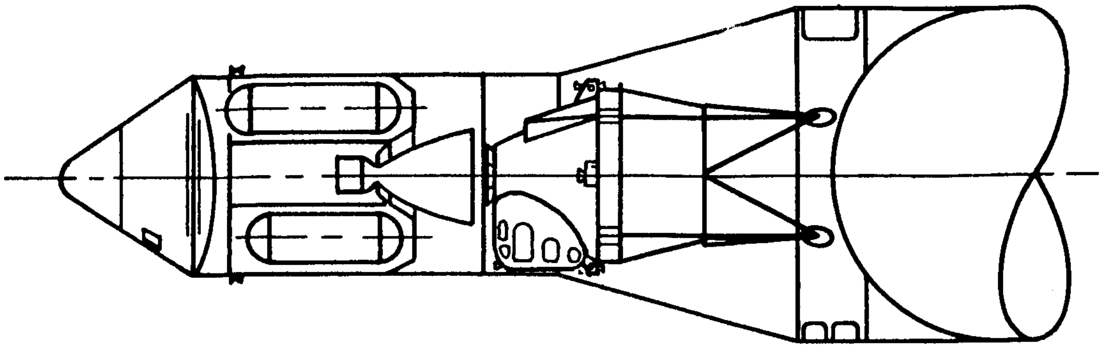
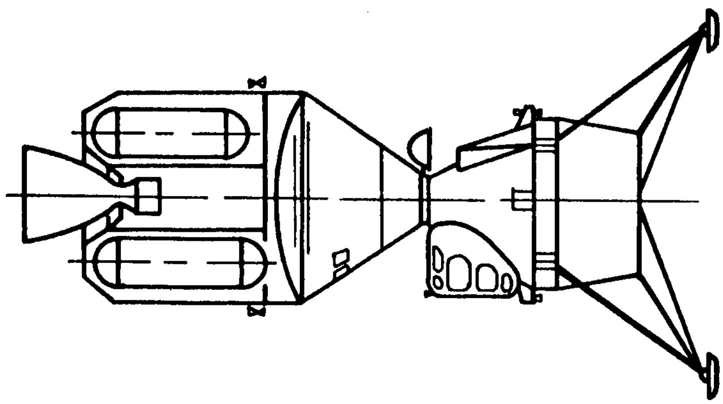


Figure 61. - Lunar excursion module external configuration

[redacted]



Stowed configuration



Translunar configuration

Figure 62. - Spacecraft flight configuration

[redacted]

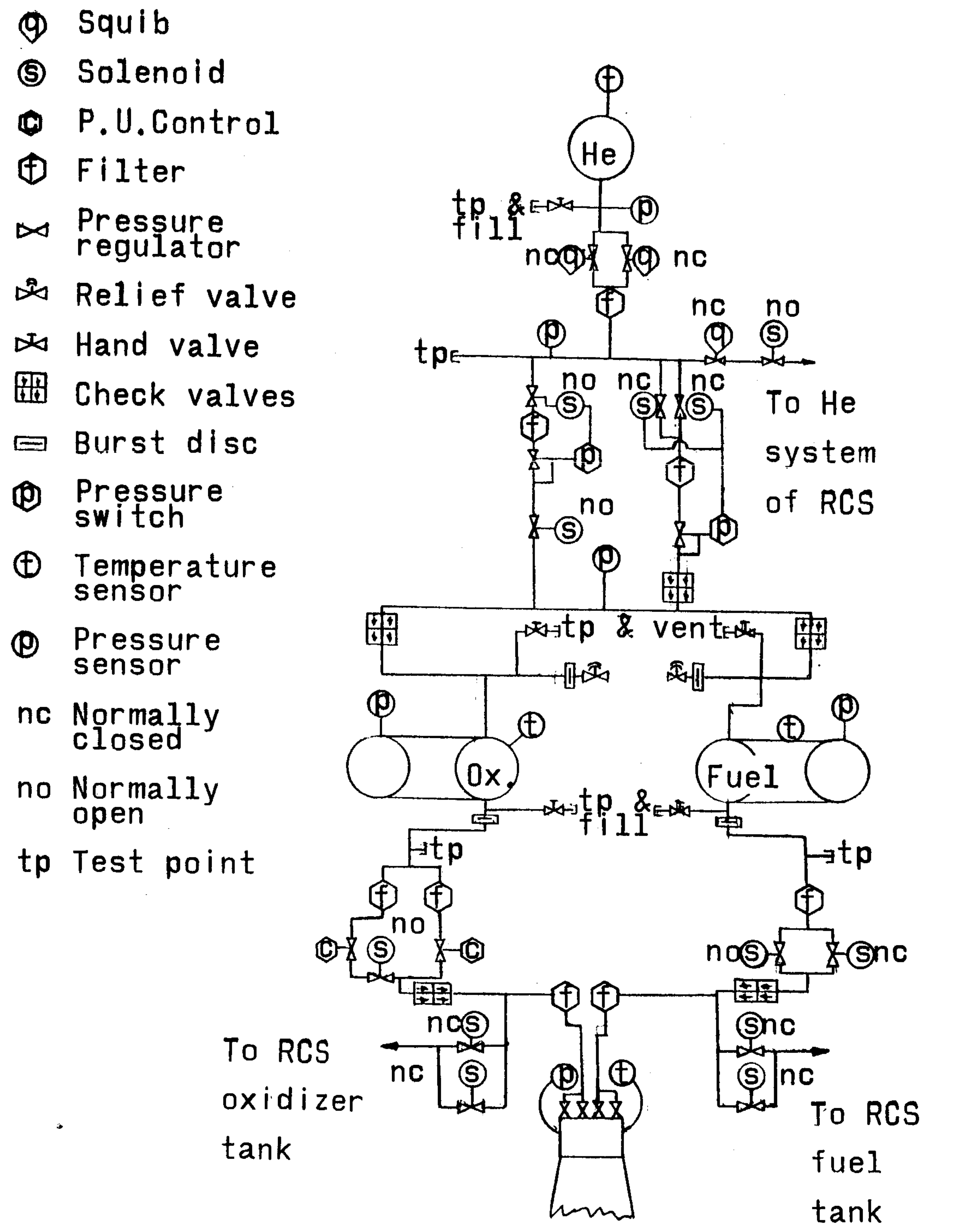


Figure 63.-Service propulsion system, Single chamber

[redacted]

[redacted]

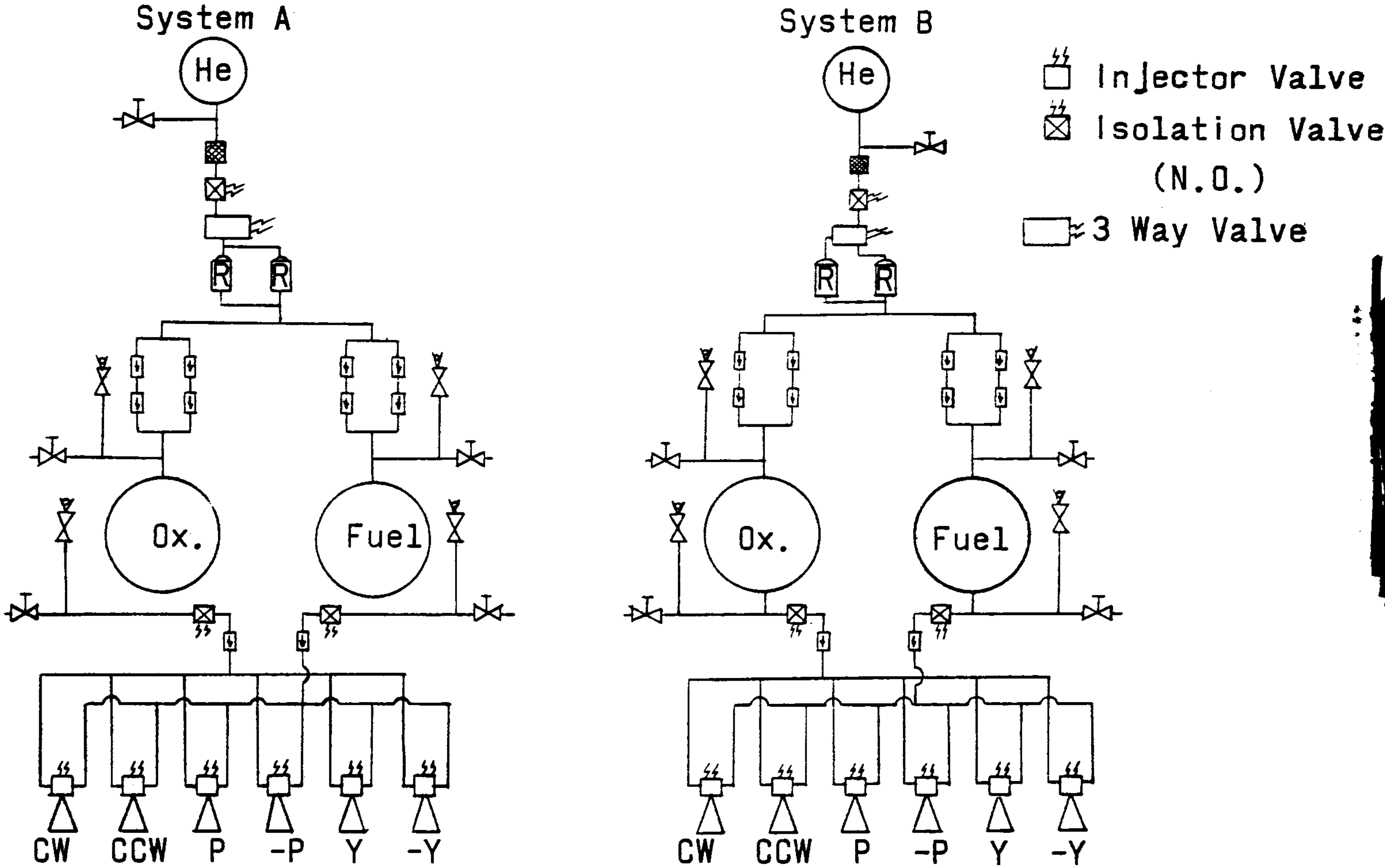


Figure 64. - Reaction control system, command module, schematic.

[redacted]

[redacted]

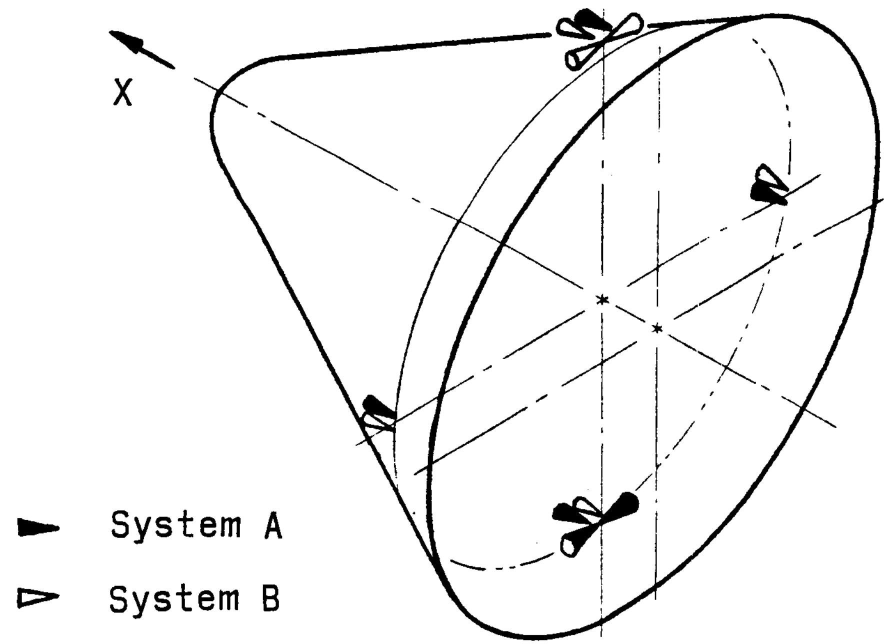
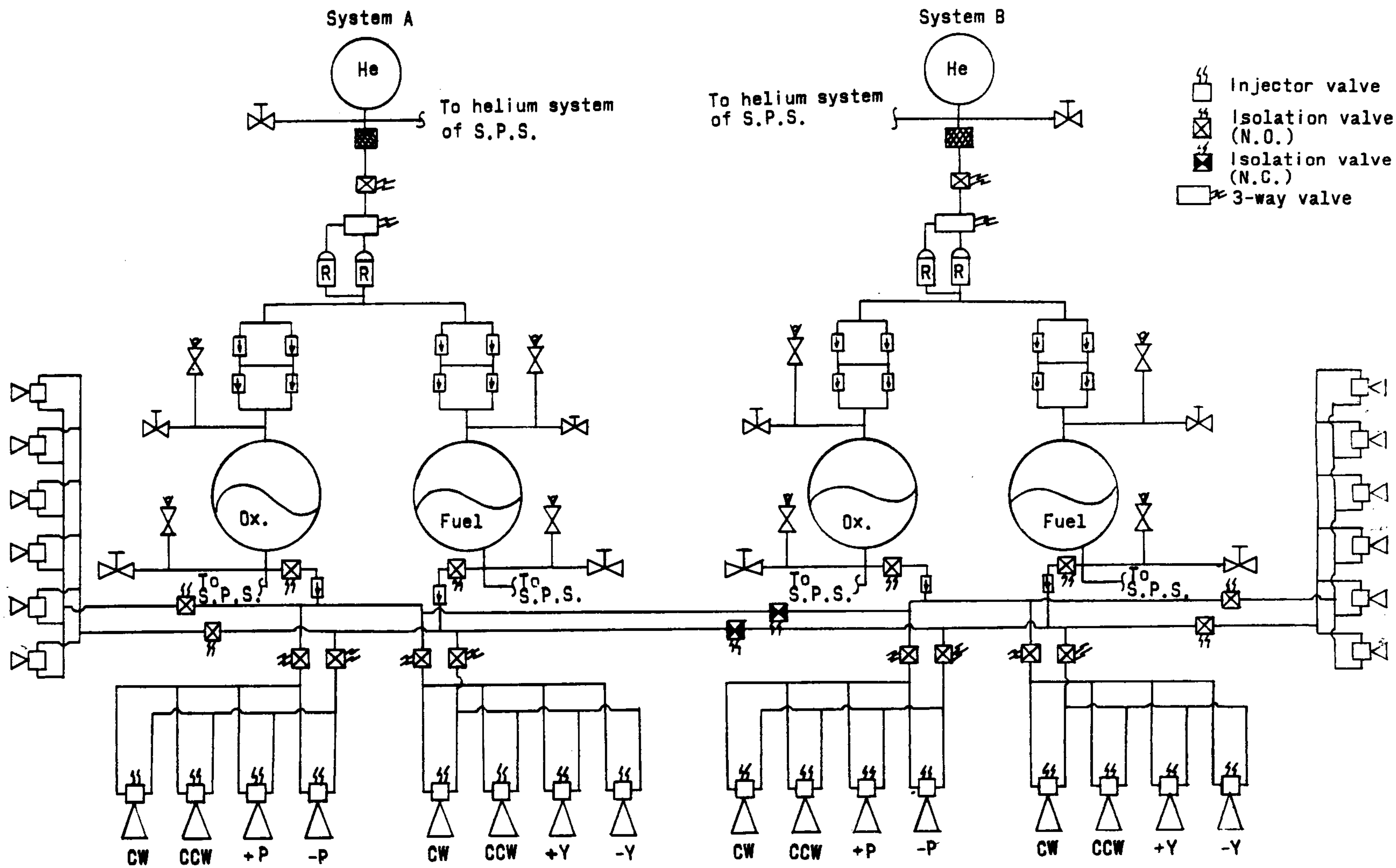


Figure 65.- Reaction control system - Command module -
thrust chamber positions

[redacted]

[redacted]



[redacted]

Figure 66- Reaction control system, service module.

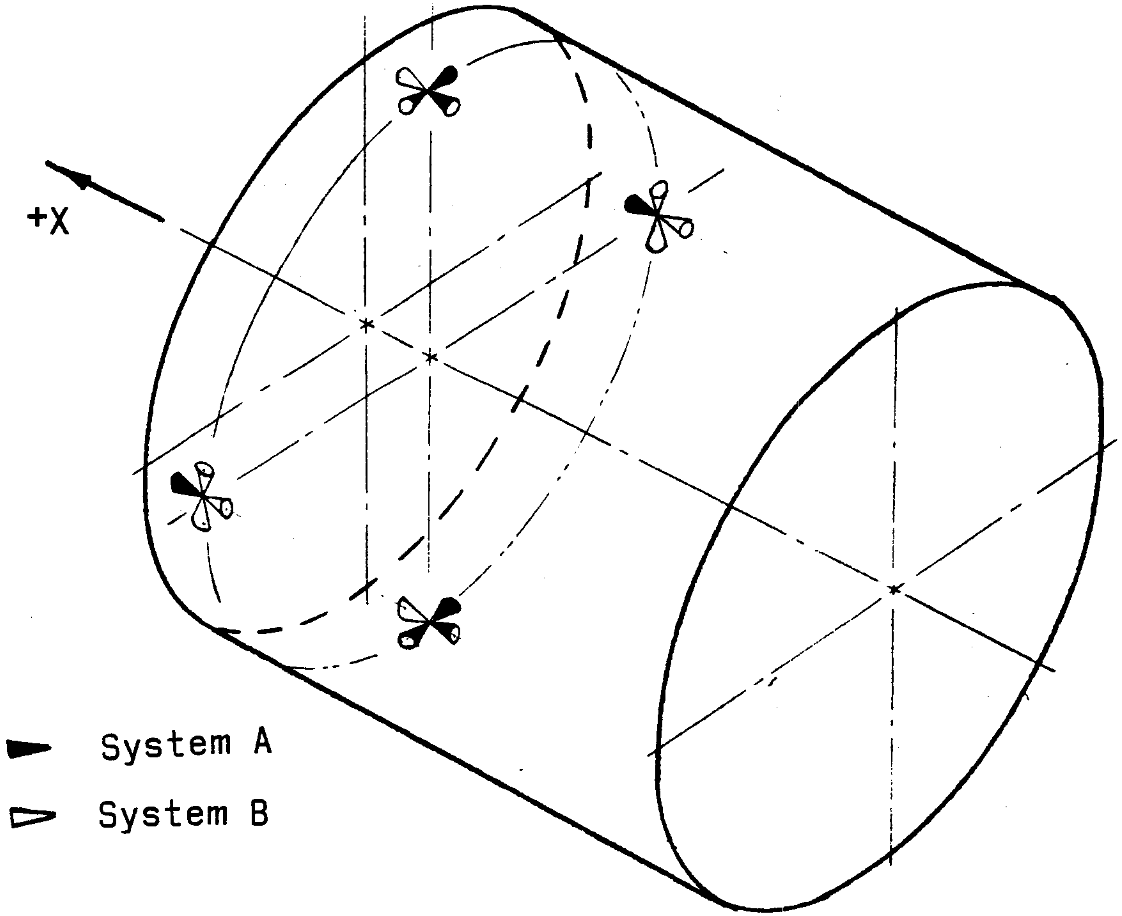


Figure 67.- Reaction control system, Service module, thrust chamber positions

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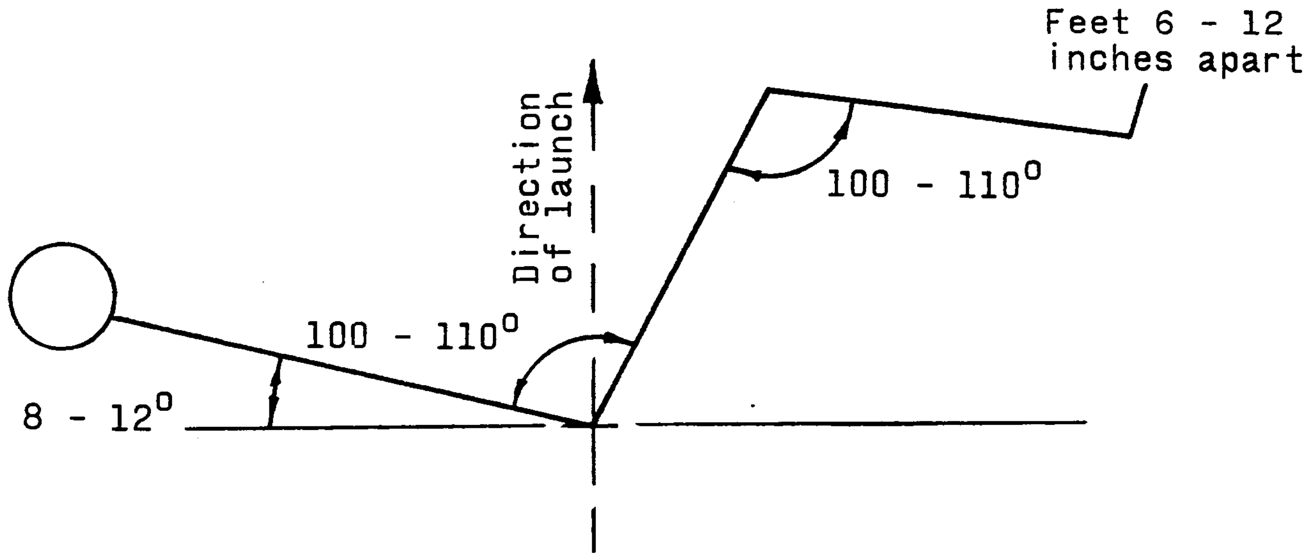

Upper arm parallel to trunk
elbow interior angle approximately 135°

Figure 68.- Body angles

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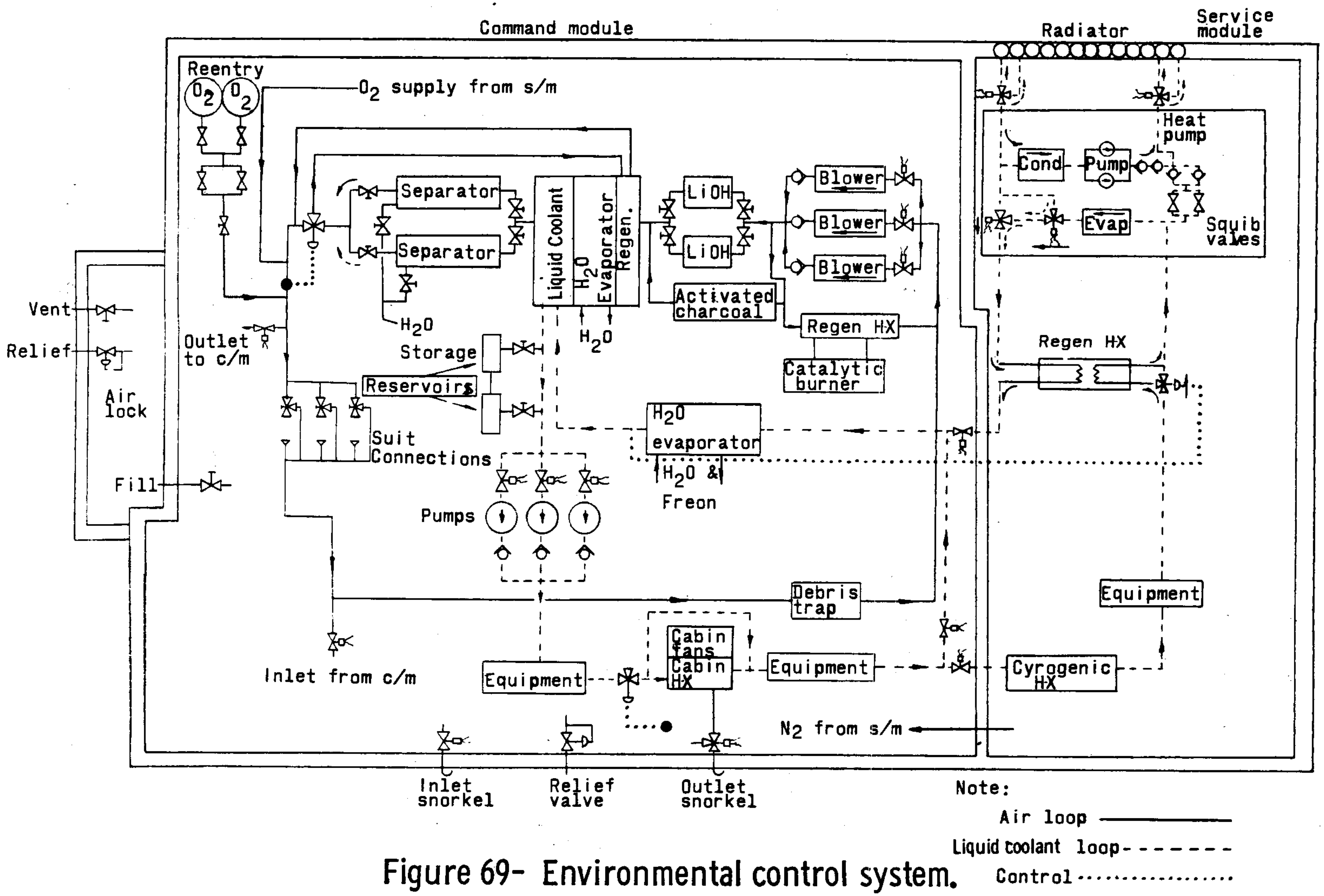

Figure 69- Environmental control system.

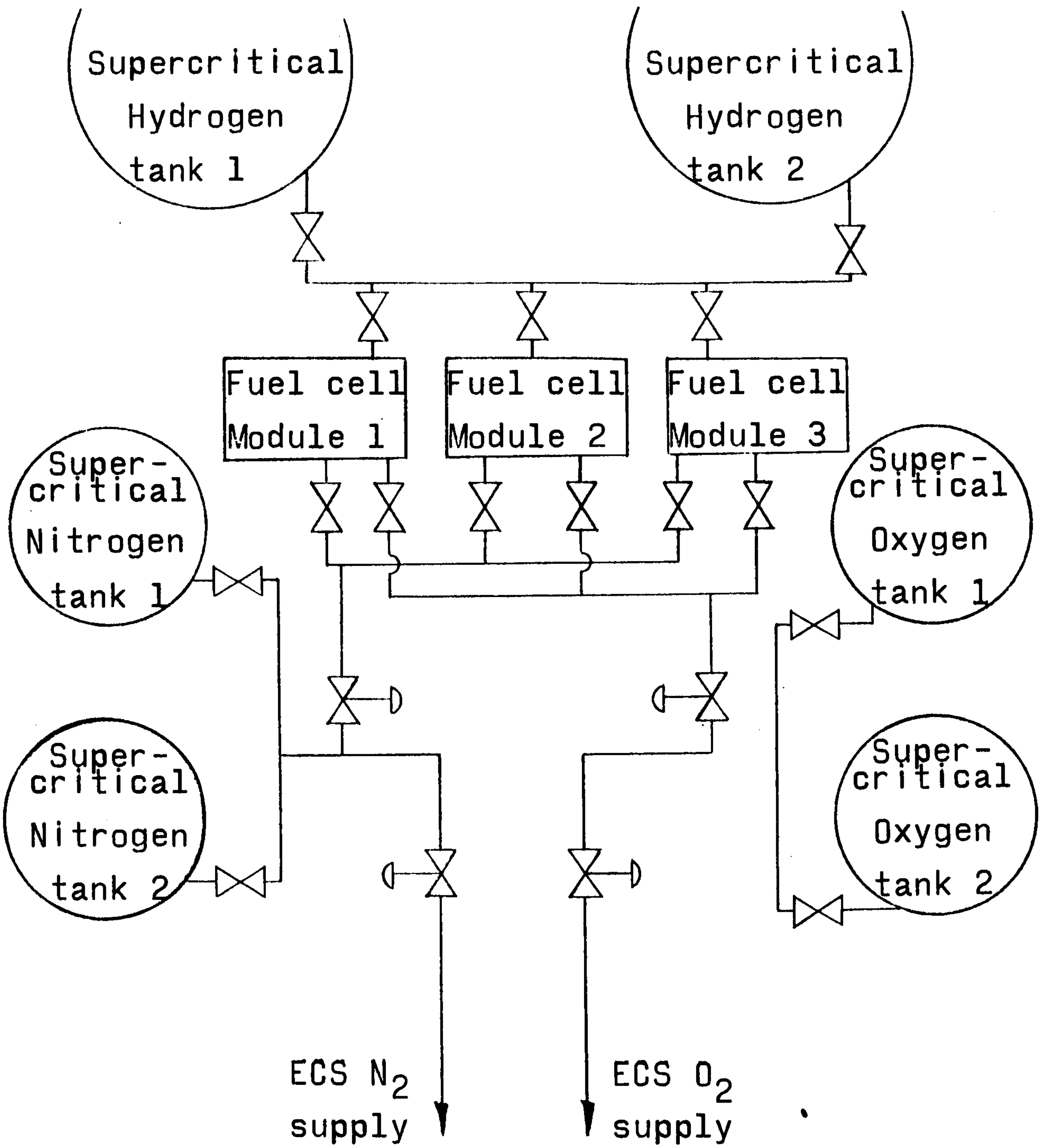

Figure 70.- Electrical power system - schematic.

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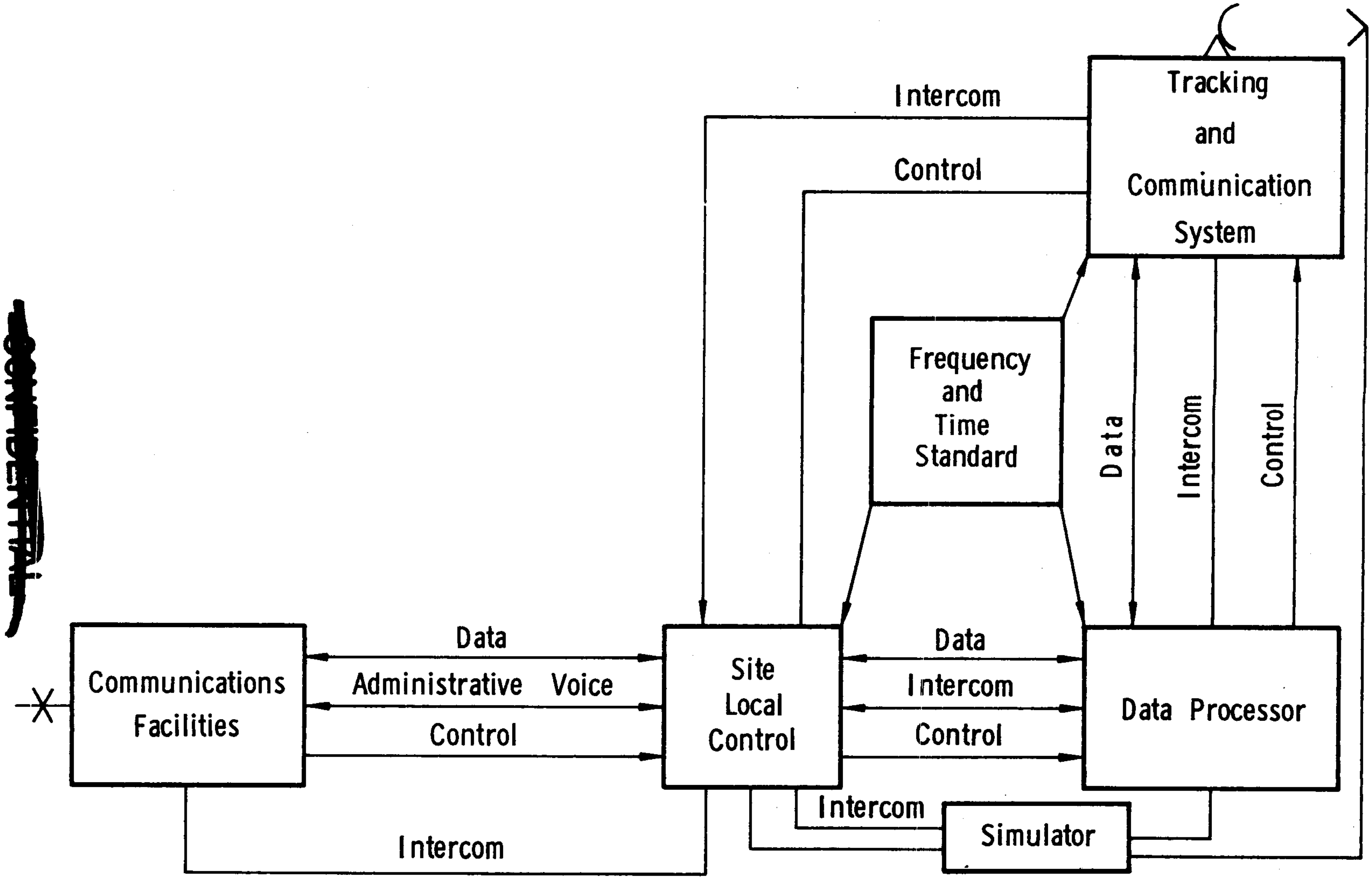

Figure 71- Functional layout to GOSS station.

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Data Lines Tracking and Communications Data Processor

Voice	⟷
TM (D)	⟶
TM (U)	⟵
Range	⟵
Range Rate	⟵
Azimuth	⟵
Elevation	⟵
Status	⟵

Local Control - Ground Communication Facility

Voice	⟷
TM (D)	⟶
TM (U)	⟵
Range	⟷
Range Rate	⟷
Azimuth	⟵
Elevation	⟵
Status	⟶

Data Processor - Local Control

Voice	⟷
TM (D)	⟶
TM (U)	⟵
Range	⟷
Range Rate	⟷
Azimuth	⟷
Elevation	⟷
Status	⟶

LEGEND

⟷ = Two Way Communication
⟶ = One Way Communication

Figure 72. - Data flow at GOSS station

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